Bridge Barrier Retrofits in New Zealand

Peter McCarten, Group Technical Leader, Opus International Consultants Ltd
and
Rudolph Kotze, Bridge Manager, New Zealand Transport Agency

SYNOPSIS

Historically New Zealand bridges relied on concrete kerbs to provide re-direction of wayward vehicles. Typically the side protection for these older bridges consists of a solid kerb with a set back concrete post and handrail system. Recently New Zealand Transport Agency adopted NCHRP 350 and crash performance testing of barrier systems for barrier ‘design and selection’. Evaluation of the older rigid bridge barrier system has shown it typically only provides a Test Level 2 collision performance. Recent risk studies for barrier selection have shown the TL2 barrier performance to be inadequate for current traffic volumes, vehicle weights and vehicle travel speeds on state highway bridges and hence barrier upgrading can often be justified. Designers responsible for designing a bridge barrier retrofit system are required to do so from first principles and acceptance of the proposed barrier system falls to the Road Controlling Authority, since the cost of crash testing is significant. New Zealand Transport Agency recognised these issues and has undertaken a project to prepare a guideline document to not only ensure consistency in the design of bridge barrier retrofits but also in the evaluation of the existing bridge using a design philosophy to optimise the structure asset management outcome. The proposed evaluation and barrier design procedures and principles integrate international best practice and provide a rational and consistent method for designing semi-rigid barriers for a range of barrier collision performance. The guideline also includes a range of acceptable solutions, for different collision performance barriers and the associated transitions, with the aim to achieve industry wide standardisation and value-for-money.

INTRODUCTION

In New Zealand it is recognised that the transport sector must ensure ‘people and freight’ have access to an affordable, integrated, safe, responsive and sustainable transport system. The Government Policy Statement (2008) (GPS) sets out specific guidance under a 10 year programme and this includes reducing fatalities and requiring there be no deterioration in reliability of critical routes by 2015. The GPS also requires “making best use of existing networks and infrastructure” and bridge barrier retrofits fit well to these GPS visions and requirements.

For Road Controlling Authorities (RCA’s) to show good stewardship of all road assets they must be able to manage all aspects of asset performance. The management of road structural assets requires targets to be set, monitored, measured and the outcomes reported for all aspects of the structure reliability and this typically includes condition and risk. Bridges by their nature are complex structural systems which are
designed and constructed to provide a range of levels of service. The as-built bridge must have sufficient strength, stiffness, ductility and durability to accommodate the environmental hazards (e.g. floods and earthquakes) to which the bridge will be subjected. The bridge must also have sufficient strength, stiffness, ductility and durability to accommodate accidental hazards (e.g. road collision at deck level, vessel/vehicle collision at substructure level and associated consequences, e.g. explosion or fire). In order to manage these risks the RCA must be able to show they have quantified them in a consistent manner, evaluated the risks for acceptability against the target levels of service and developed an appropriate improvement programme to ensure consistency in network wide bridge performance. A critical component of all bridges, which can impact directly on road user safety as well as structure safety, is the bridge barrier. Bridge barriers in New Zealand have evolved with time and the details used have been strongly influenced by construction practices, proprietary component availability and road user demands, including vehicle type and size, vehicle speed and road user expectations of collision performance. Since the late 1960’s semi-rigid barrier systems using W-beam and more recently Thrie beam have commonly been used.

The New Zealand Transport Agency has recognised that bridge barrier design generally needs to be from first principles due to the lack of tested systems and this has resulted in inconsistent standards within the network. In order to overcome this variability in design standard and to achieve consistency in evaluating existing bridges for semi-rigid barrier collisions a guideline document has been produced and issued to the industry. This paper outlines the development of the guideline document and provides details of the guide content.

BACKGROUND

Historically bridge designers in New Zealand have recognised the variations in road user risk at bridge sites and the side protection was adjusted to suit. Typically the bridge side protection consisted of a Kerb, used as the dominant vehicle re-direction device, with a handrail behind. A range of kerb types were available consisting of different materials and of two main forms, an ordinary kerb and a safety kerb, and these could be combined with a range of handrail types consisting of different materials with different degrees of robustness. The design essentially followed a ‘best practice’ selection process. While the historic existing bridge stock has a range of side protection systems they are of similar design collision performance in terms of current vehicle collision knowledge.

In 1998 the New Zealand Transport Agency adopted North American practice for safety performance evaluation of New Zealand highway features and the principles also apply to bridge barriers. The guideline report NCHRP 350 (1993) sets out the details for evaluating many highway features including longitudinal barrier performance and the following requirements are defined:

- Test vehicle types, sizes and characteristics
- Collision speeds, barrier incidence angles and the location of impact points are all defined, with these set depending on the Test Level Collision performance required for the barrier or feature being tested
• Criteria for data measurement and recording
• Criteria for evaluating the test data and determining acceptability
• Performance of different sections of the barrier tested – length of need and transitions

In order to define different collision performance NCHRP 350 uses a Test Level (TL) rating system with this ranging from a low restraint TL1 to a high restraint TL6 system.

With the New Zealand Transport Agency adopting NCHRP 350 (1993) there is now a rational methodology and process for designing bridge barriers specific to site requirements. In order to avoid design detailing variation and achieve industry consistency the decision was made to only accept tested and approved barrier systems. While this longitudinal barrier policy fitted well for roadside barriers it did not take into account the lack of testing on bridge barrier systems. To overcome this lack of information on bridge barriers the New Zealand Transport Agency supplemented the Bridge Manual, which at that time only included specific design for a ‘deemed acceptable’ TL3 barrier system, with specific guidance on a semi-rigid TL4 barrier, adopting the Modified G9 system specified in AS/NZS 3845 (1999), as well as providing guidance on a range of rigid barrier systems and specifying the collision load requirements for rigid barrier systems. These Bridge Manual (2004) amendments have ensured new bridge design achieves consistency for the respective bridge barrier designs but they did not address the design requirements for existing bridge barrier retrofits.

In 2006 the New Zealand Transport Agency determined there would be benefits in undertaking a review of current bridge barrier retrofit design practice, identify ‘best practice’ and compile a guideline (the guide) document for industry use, with it setting out design principles and a range of acceptable solutions. New Zealand Transport Agency engaged Opus International Consultants Limited to undertake this work. The first stage of this commission was a survey of the bridge industry to gauge interest in the project and get feedback on practices used to date. The survey included not only the New Zealand Transport Agency Regional Bridge Consultants, managing the state highway bridge stock, but also the wider group of New Zealand bridge consultants undertaking most of the bridge design work in New Zealand. The feedback from the survey was good with 92% response and all respondents supporting the initiative. The example retrofit and new barrier designs submitted gave a good range of good and bad details reinforcing the design concerns held. The survey respondents strongly supported the need for a range of semi-rigid (W-beam and Thrie beam) bridge barrier retrofit solutions.

The survey respondents while recognising the general need for bridge barrier retrofits requested more information for justifying bridge barrier retrofits. The survey raised the following concerns or requests for guidance:

• The combination of semi-rigid barriers with rigid concrete kerbs is generally not preferred
• Guidance on bridge barrier performance and design requirements
• Guidance on barrier positioning
• Guidance on the process for selecting a barrier collision performance, recognising the need to optimise costs and benefits
• Guidance on the methodology required for evaluating the adequacy of the existing bridge
• A range of acceptable solutions was requested

The paper discusses each of the above technical matters before summarising the overall content of the guide.

JUSTIFYING BRIDGE BARRIER RETROITS AND THE SELECTION PROCESS

Early in the bridge barrier retrofit project it was agreed the guide document would not provide specific policy on when or when not to undertake a bridge barrier retrofit but it was agreed the guide would provide sufficient information to allow technical acceptability of the existing barrier to be determined.

When a bridge barrier retrofit is being assessed there must be a clear and focused understanding why the retrofit is required and what must be achieved to realise the benefits of the retrofit. Typically there are two main reasons for bridge barrier retrofits, they are:

• asset management where on-going vehicle collision damage costs and risks are excessive for the existing barrier and a retrofit will reduce the likelihood or severity of damage, or reduce the cost of repair
• safety where the existing barrier is unsafe, due to inadequate strength or details, or offers a lower NCHRP 350 (1993) collision performance than required for the site

The following are considered acceptable reasons for justifying bridge barrier retrofits:

• an increase in pedestrian or cycle traffic requiring their separation from the vehicle traffic for safety reasons
• handrail systems that do not have sufficient strength to comply with Bridge Manual (2004) load requirements

Figure 1: Typical Kerb and Handrail configurations on New Zealand bridges.
• kerbs that do not have sufficient strength to comply with the Bridge Manual (2004) requirements
• kerbs that do not have sufficient height for vehicle re-direction
• kerbs that have a ‘flat’ face slope allowing ready vehicle mounting

The standard concrete bridge kerb through the 1940’s to the 1960’s was 250mm high and with a 250mm offset to the face of the handrail, safety kerbs had a 530mm offset to the handrail. Two of the common existing bridge side protection systems are shown in Figure 1. The ‘rigid’ concrete handrail and kerb system for typical bridge deck designs has been back calculated using the Bridge Manual (2004) rigid barrier collision loads and it has been determined they typically only provide TL2 collision performance. Recent risk studies for barrier selection have shown that TL2 barrier collision performance is inadequate for current traffic volumes, vehicle weights and vehicle travel speeds on state highway bridges and this provides further justification for barrier upgrading.

With bridge barrier justification is the issue of selecting the optimum barrier collision performance for the retrofit. The guide sets out a three stage process, being:

• determine the preferred barrier collision performance assuming the site is ‘greenfields’ using the procedure in the Bridge Manual (2004)
• evaluate the existing bridge to determine the strength available and the collision performance that can be achieved without superstructure strengthening
• if the preferred barrier collision performance is higher than that available then determine the optimum considering superstructure strengthening options

The selected barrier collision performance will hence be either the preferred barrier collision performance or the optimum. The New Zealand Transport Agency has requested all bridge barrier retrofits be subject to their approval and the guide sets out the requirements for the approval process.

KERBS

Kerbs have been used in road construction for many years. Roman Roads used kerb stones to provide edge definition, side support and drainage control. The 1971 Federal Highway Administration Bridge Inspectors Training Manual defined a kerb as guiding the movement of vehicle wheels to safeguard bridge trusses, railings and other construction outside the roadway. However over the last 30 years with the change in vehicle type, increase in Heavy Commercial Vehicle (HCV) weight and increase in travel speeds the use of kerbs, particularly in conjunction with other side barrier devices, has been discouraged.

As part of the bridge barrier retrofit project a detailed study of the kerb type, height and usage on bridges within the state highway network was undertaken by interrogating the New Zealand Transport Agency Bridge Descriptive System. The New Zealand Transport Agency was responsible for 2406 bridges (excluding bailey bridges and large culverts) in 2007 and it was found that 52% of these have at least
one kerb. The analysis of kerb height showed 80% of the bridges had a kerb height between 200mm and 300mm, 2% of the bridges had a kerb height of 100mm or less.

Kerbs are an integral part of the deck and bridge superstructure. The structural enhancement effect of kerbs has been reported by Buckle et al (1985) which was based on testing to destruction three New Zealand bridges in the late 1970’s and early 1980’s. Based on that research it is considered that the kerb should be retained if all the following are available:

- the kerb concrete and reinforcing is integral with the bridge deck and of adequate structural capacity
- kerb concrete and reinforcing is in good condition
- deck edge concrete and reinforcing is in good condition

If the kerb height is less than 150mm then the structural enhancement is not considered significant and the kerb could be removed. Hence 50% of the bridges in the network have a kerb that will need to be taken into account for any bridge barrier retrofit.

Typically the handrail components for bridge barrier retrofits have defective condition, either by collision damage or by age and corrosion effects, and are not integral with other handrail components. It is considered the handrail has less impact on structure strength and its removal can be included as part of a bridge barrier retrofit.

The New Zealand Transport Agency Draft Geometric Design Manual aligns with international practice by discouraging the use of kerbs on high speed roadways due to the potential to cause drivers to lose control in a crash, it is also recognised Kerbs can cause an out of control vehicle to roll over. There are many situations where kerbs are a desirable feature and NCHRP 537 (2005) investigated the crash performance of kerbs to develop recommendations for combinations of kerbs and strong post guardrail systems and the set out requirements for a range of vehicle speeds. While NCHRP 537 (2005) was limited in its investigation of kerb configurations, the kerb height was limited to a maximum of 150mm, some of the report findings were considered relevant to the higher bridge kerbs. The NCHRP 537 (2005) recommendation on barrier face positioning above the kerb face of a non-mountable kerb in high speed sites was accepted. The guide has adopted a non-mountable kerb as one with a kerb face of $1/4:1$ or steeper.

The study of the structural capacity of the kerbs identified changes in reinforcing with changes in standards and identified that care would be needed in some instances for transferring concentrated barrier post loadings into the superstructure. It was decided the guide would need to include standard post fixing details for different kerb configurations and the range of acceptable barrier solutions.

Due to the safety issues related to combining semi-rigid and rigid kerbs it was decided to develop barrier details that would limit lateral displacement in the design collision to 300mm, as this related well to back calculation of the approved barrier systems. A submission was made to the New Zealand Scope and Standards Committee on this aspect of the project and their approval was obtained.
BARRIER PERFORMANCE AND DESIGN

The New Zealand Transport Agency required the guide to provide sufficient information to ensure designers of bridge barrier retrofits were aware of the fundamental requirements so the implications of detail changes could be understood. The barrier performance must meet the general requirements of NCHRP 350 (1993) and these have been promulgated through various guides and specifications. In the bridge barrier retrofit project use has been made of LRFD (2007), Colosimo (1997) and AS/NZS 3845 (1999) and the summary of the guide requirements is given below:

- contain and smoothly redirect the design vehicle
- provide the full lateral strength specified and ensure the tensile strength of the barrier is provided continuously over the length of the barrier
- provide appropriate transitions of compatible stiffness to the bridge barrier and detailed to minimise effects of objects in the collision zone. 1:10 barrier tapers have been adopted
- have sufficient strength during vehicle impact and details to minimise the risk of components spearing the compartment or becoming airborne projectiles
- be capable of rapid repair or replacement
- provide for the thermal, rotational and other barrier and structure movements
- be detailed to harmonise with the structure avoiding obstruction of view or vehicle occupant site distance
- be detailed to minimise hydrodynamic forces or debris trapped if overtopped
- be detailed to limit ice in trafficked areas

Semi-rigid barriers are also required to meet the following geometric requirements:

- the total depth of the longitudinal barrier components including the rail and kerb above the reference surface expected to be in contact with the vehicle ($\sum A$) is to be greater than 25% of barrier height (H), where H is the height from the top of the rail to the reference surface
- the clear vertical opening below the lowest rail shall be less than 380mm
- the clear vertical opening between rails shall not exceed 380mm
- unless otherwise approved by New Zealand Transport Agency posts shall be set back from the traffic face of the barrier the following distances:
  - 100mm for $\Sigma A/H \geq 0.5$
  - 200mm for $\Sigma A/H \leq 0.3$
  - linear interpolation used when $0.3 \leq \Sigma A/H \leq 0.5$
- if traffic faces of rails within a barrier are more than 25mm back from the barrier face line then that rail shall not be considered as contributing
- when the cross fall slope on the bridge deck is greater than 3% the barrier set out line shall be perpendicular to the deck cross fall

Three further aspects of barrier design that need to be considered are deck surface drainage, transitions and longitudinal anchorage for long barriers and the guide gives specific guidance on each of these matters.
EVALUATING THE EXISTING BRIDGE STOCK

The New Zealand Transport Agency Bridge Manual (2004) sets out the design philosophies and specific requirements for new bridge design, including the rigid barrier load requirements and deemed acceptable TL3 semi-rigid barrier load requirements. The Bridge Manual (2004) also includes a section on evaluating existing bridges with a focus on traffic loads but no guidance is given for evaluating existing bridges for barrier vehicle collision loads. The bridge barrier retrofit project needed to address the following:

- define the loads to be used
- define the load combinations for the evaluation
- develop specific guidance for the load analysis
- define the material properties to be used
- define the method for section strength assessment

As for any bridge evaluation there is a need to obtain reliable as-built records and assess existing bridge condition and these requirements are specified in the guide.

The main aims of the evaluation process are twofold, as follows:

- to meet the Bridge Manual (2004) design philosophy that barrier post knock-off and full barrier tension will develop without significant damage occurring to the deck and superstructure
- to determine the existing bridge failure hierarchy in a consistent manner so that strengthening work and costs can be quantified should the strength required for the preferred barrier collision performance not be available in the existing bridge, allowing optimisation of the bridge barrier retrofit work

The loads to be applied are clearly deck and barrier dead load, vehicle loadings and the barrier collision load. With reliable as-built records the dead load actions are readily defined. The Bridge Manual (2004) defines the traffic loads to be used when designing for a TL3 barrier system. Following a review of historic New Zealand traffic load configurations as well as international practice, LRFD (2007), the application of a 60kN HN load footprint perpendicular to the barrier face with the footprint edge aligned immediately below the barrier face with a Dynamic Load Factor = 1.0 was adopted. The guide requires the evaluator to assess whether the bridge under evaluation has ‘normal’ deck roughness and should a higher roughness be considered appropriate then the traffic load is to be adjusted by applying a 1/1.3 multiplier.

Barrier collision loads transferred to the superstructure are governed by the post and the fixing strength. It was necessary for the bridge barrier retrofit project to develop the Minimum Barrier Collision Loads for use in bridge evaluations and for designing barrier posts and fixings and a pragmatic method was used. The Bridge Manual (2004) sets out the load requirements for the ‘deemed to comply’ TL3 barrier and this set the lower bound collision loads.
A review of the Federal Highway Authority approved barrier systems identified the Delaware kerb mounted Thrie beam rail retrofit as being tested to TL4 collision performance. This system has the barrier face in line with the kerb face, a height to top of the rail of 815mm (32inch), 3.4mm Thrie beam barrier on a 205mm (8inch) kerb. Back calculation of that system has generated the TL4 barrier collision loads for the guide. The geometric dimensions for the adopted TL4 barrier have been aligned to match current industry practice and Bridge Manual (2004) requirements and hence differ slightly from the Delaware system.

Based on the loads for these two collision performance levels a simple energy based model was developed so barrier collision load levels for a range of TL collision performance could be predicted. This method was also checked using the first principle plastic method of analysis for barrier and post design. The adopted loads are presented in Table 1.

<table>
<thead>
<tr>
<th>NCHRP 350 Test Level</th>
<th>Barrier Type</th>
<th>Barrier Centreline Height (mm)</th>
<th>Outwards (kN)</th>
<th>Inwards (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>W-Beam</td>
<td>550</td>
<td>45</td>
<td>19</td>
</tr>
<tr>
<td>3 High</td>
<td>Thrie Beam</td>
<td>615</td>
<td>50</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>W-Beam</td>
<td>615</td>
<td>50</td>
<td>21</td>
</tr>
<tr>
<td>4</td>
<td>Thrie Beam</td>
<td>615</td>
<td>60</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>W-Beam</td>
<td>710</td>
<td>55</td>
<td>21</td>
</tr>
<tr>
<td>4 High</td>
<td>Thrie Beam</td>
<td>815</td>
<td>60</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>W-Beam</td>
<td>815</td>
<td>60</td>
<td>27</td>
</tr>
</tbody>
</table>

Table 1: Minimum barrier collision loads for semi-rigid barriers.

The load combination adopted from the bridge barrier retrofit project is

\[ 1.2 \ D + 1.35 \ LL + 1.1 \ CO \]

Where

- \( D \) = Dead Load
- \( LL \) = Live Load
- \( CO \) = Collision Load

The form of this load combination aligns well with that used in the Bridge Manual (2004) and the load factors typically include a 10% reduction over designing new to be consistent with the evaluation section. The load combination also recognises that the Class 1 twin tyre legal HCV in New Zealand is limited to 8.2 tonne/axle or 4.1 tonne/wheel and the load combination above provides an effective load factor of 2.0 to this wheel load. The load combination recognises that in a collision load case the loads are localised and the deck loadings are governed by wheel load effects.
For section capacity assessment the bridge barrier project considered nominal strength, probable strength and over strength. In view of the extreme nature of the load case it was deemed appropriate to adopt probable section strength for evaluation. Many as-built plans do not provide details of the reinforcing tensile strength and hence simplified procedures are desirable. The Bridge Manual (2004) includes a summary of the material characteristic strength to be assumed, depending the age of the structure, should as-built data not be available. In this project the adjustment from characteristic to probable strength is given by the following:

\[ f_y (\text{Probable}) = 1.1 \times f_y (\text{Characteristic}) \]
\[ f'_c (\text{Probable}) = 1.3 \times f'_c (\text{Characteristic}) \]

Other than the change in material properties the method of section strength assessment is to be in accordance with available material design standards. The section capacity is to take flexure, shear and tension (caused by the outward collision load) into account.

The final issue for existing bridge evaluation is the method of analysis or load spread into the superstructure. From a review of international practice the LRFD (2007) simplified yield line approach using 45 degree load spread was adopted. The guide sets out the criteria for use in determining the available section size for section capacity assessment.

![Figure B8: Threshold Limits 100 km/h](image)

Figure 2: Modified version of the Bridge Manual (2004) Figure B8 incorporating the proposed TL3 High and TL4 High bridge barrier systems
ACCEPTABLE SOLUTIONS

In order to achieve consistency and value-for-money with bridge barrier retrofits a range of acceptable solutions have been developed. The selection of an acceptable solution follows the process outlined in the guide. Acceptable solutions will receive expedited approval from the New Zealand Transport Agency if it is accepted in its entirety. For new bridges the Bridge Manual (2004) sets out a procedure for barrier selection and this is based on the use of an appropriate Threshold Limit Figure, refer to Figure 2 which includes a modified version of Fig B8 Threshold Limit 100km/h from the Bridge Manual (2004).

In developing the bridge barrier retrofit project we found from the bridge evaluation that typical existing bridges had more strength available than that required for TL3 but they were unable to accommodate TL4. It was observed, refer to Figure 2, that for many New Zealand state highways the AADT approximates 5000vpd and a TL4 barrier was not required and this gave justification for developing intermediate collision performance barrier systems. These two observations have led to the development of the TL3 High and TL4 High barrier systems. The barrier height and minimum collision load requirements are set out in Table 1. It can be seen from Table 1 that these intermediate barrier systems have had their height set at the next higher TL but the strength demand has been set intermediate to the adjacent collision performance levels. Another advantage of the TL3 High system is it makes use of available 2.7mm Thrie beam.

Figure 3: Chart setting out the guide limitations for the range of bridge related barrier modifications

THE GUIDE DOCUMENT

The technical requirements for the guide have been given in the preceding sections of this paper. The New Zealand Transport Agency had requested the guide be
prepared for easy use. With the outcome of the bridge barrier retrofit project becoming defined final decisions on format, design aids and presentation were made. It was decided to adopt a ‘step by step’ design process layout and develop many charts, refer to Figure 3, and design aids to enhance guide use. With the format adopted it is considered it will be more readily applied by all engineering staff.

CONCLUSION

The main aim of this paper is to present the process and findings of the bridge barrier retrofit project undertaken by the New Zealand Transport Agency. As the project evolved there was a change from presenting a range of ‘best practice’ examples to developing more robust processes for bridge barrier selection, existing bridge evaluation for collision loads and for bridge barrier retrofit design, as well as developing a range of acceptable solutions. The paper outlines the verification and calibration work that was undertaken through the project as well as setting out the justification for the development of new, TL3 High and TL4 High, bridge barrier systems. The interim guide, recently released for industry use and feedback, has received good reviews to date. It is concluded the bridge barrier retrofit project undertaken has been worthwhile, the Government Policy Statement (2008) requirement to make best use of the existing networks will be met and the aims to achieve industry wide standardisation and value-for-money are expected to be realised.

REFERENCES


