ENHANCING BRIDGE SAFETY FOR MOBILITY IN SOUTHERN AFRICA: A STUDY OF INTERNATIONAL IMPACT PROTECTION DESIGN PRACTICES

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ABSTRACT

This paper investigates international design practices for impact protection in bridges, focusing on enhancing safety for Southern African infrastructure.

The study analyses impact protection works, such as barriers and other structures, designed to safeguard existing bridges from vehicle collisions, particularly impacts involving piers and supports. It references design criteria from Section 4.12.13 of Queensland's *Design Criteria for Bridges and Other Structures*, AS 5100, Eurocode, and AASHTO. The paper explores how these international standards can be applied to enhance bridge safety practices in South Africa.

By evaluating the effectiveness of these design practices, the study aims to recommend best practices for vehicle impact protection that can be incorporated into South African bridge regulations.

The recommendations seek to reduce the risks posed by vehicle collisions and enhance overall bridge safety, contributing to more resilient and secure transportation infrastructure in the region.

Keywords: Bridge impact protection, Vehicle impact protection, Bridge safety standards, Design practices, Barriers, Reduce vehicle collision risks.

1. INTRODUCTION

Pier impact assessments are conducted on existing bridges for several reasons, such as when underpass widening reduces the clearance between the road and bridge supports, or when modifications to the bridge substructure are made. Existing bridge supports (piers and foundations) are then assessed to ensure that the structural capacities of the existing supports are sufficient and resilient enough to not be at risk of failure. This paper investigates a comparison between pier collision loads, impact assessments and protection barriers in South Africa and Australia (TMH7:1981 and AS5100:2017), references to other codes are also included (European and American). Given that various regions in Australia have different regulations, this paper specifically focuses on the requirements in Queensland, while also referencing standards and guidelines from other regions for comparison (Victoria, New South Wales etc.). In addition, this paper explores the barrier design methodologies used in Australia and South Africa.

Building resilience to future challenges requires proactive consideration of evolving road networks and anticipated increases in traffic volumes, ensuring that bridges designed today remain capable of meeting future demands. This includes accounting for evolving requirements such as anti-throw screens, lighting, and sign structures, ensuring that new bridges are equipped to handle not just current but also future infrastructure needs. This ensures that any future bridge modification will be less invasive with reduced construction cost and risk. This approach will also have a positive sustainability outcome, where less extensive retrofitting is needed to ensure structural capacities of existing bridges are able to meet future demands.

2. BRIDGE PIER IMPACT ASSESSMENTS

When a road upgrade project is undertaken adjacent to an existing bridge, or when modifications to the bridge's substructure are made, a review of the existing bridge supports' resistance to impact must be conducted (Transport and Main Roads, 2024). A comparison between Australian and South African requirements were considered. Factors such as horizontal clearances and vehicle speeds influence the magnitude of the impact loads applied and this is also discussed. Where existing structures are not capable of meeting these impact loads, additional improvements need to be made to existing piers to increase their resilience.

2.1 Technical Criteria for Bridge Pier Impact Assessments

2.1.1 Australian Requirements

AS5100.2 Cl 11.2 specifies that the supports of a bridge that are within the clear zone as defined by Austroads Guide to Road Design, shall be designed to resist a minimum equivalent static load of 2700 kN acting in any direction in the horizontal plane. This load shall be applied 1.2 m above ground level and considered at the ULS (Standards Australia, 2017).

In addition to the requirements of the AS5100, Queensland-specific requirements are provided in the Transport and Main Roads, Design Criteria for Bridges and Other Structures (DCBoS) and are discussed below.

2.1.1.1 Queensland Specific Requirements

DCBoS Cl 4.12.13 states that existing bridge supports that are within the road reserve shall be protected from vehicle impact using an appropriate barrier system. When bridge supports are within the 10 m minimum clear zone and the speeds are greater than 80 km/h TL5 rigid barriers are required, for speeds less than 80 km/h, TL4 barriers are required as a minimum. These barriers should be designed to not transit the barrier design load to the bridge support. When bridge supports are outside the 10 m clear zone, the minimum acceptable barrier is the G9 (modified) Thrie beam.

In addition to the protection barrier, the bridge support shall be checked for the following impact loads:

- for vehicle speeds equal to 100 km/hr or higher, the bridge support shall be checked for an impact load of 2700 kN.
- for vehicle speeds less than 100 km/hr, the impact force can be reduced by a factor $(V/100)^2$, where V is the vehicle speed, but the minimum impact force shall not be less than 1000 kN.

Figure 1 below shows a plot of how the impact force varies with vehicle speed.

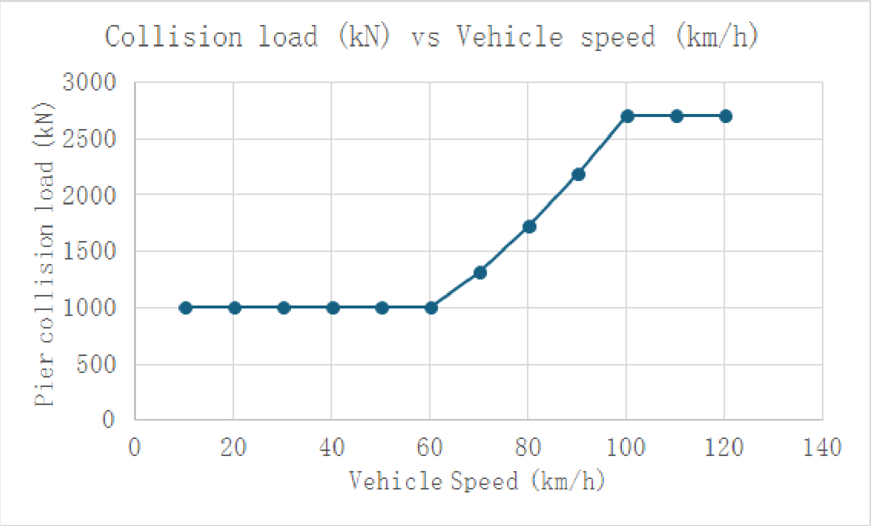


Figure 1: Graph showing the magnitude of the collision load with changes in vehicle speed

The angle of impact shall be determined by a risk analysis, but the minimum impact angle shall be 15 degrees from the direction of the road centreline passing under the bridge. The load shall be applied 1.2 m above ground level and the effective contact length is the smaller of the contact length of the support or 2.4 m. This load, in conjunction with the ultimate design dead loads on the structure, shall be considered at ultimate limit states, with a load factor of 1.0. (Transport and Main Roads, 2024).

2.1.2 South African Requirements

TMH7 Cl 3.7 states that bridge supports need to be considered for impact force damage when they are located within 8 m from the travel way and when adequate rigid barrier protection is not provided.

Nominal forces:

1. Horizontal longitudinal force = 3*v kN, subject to a minimum force of 200 kN in any direction parallel to the direction of the underpassing road. (v = design speed for underpassing roadway in km/h).
2. A horizontal transverse force of 120 kN in a direction normal to the direction of the underpassing roadway.

These forces acting simultaneously at 1.4 m above the shoulder break point level of the adjacent road. The transverse force shall be distributed longitudinally over the lesser of the length of the support or 1.5 m.

Impact forces are combined with permanent and long-term principal actions in combination 3 (not coexisting with other supplementary actions or primary live loads) with a ULS factor of 1.25 and an SLS factor of 1, multiplied by the partial load factor (λ_{f3}) = 1.1 (Committee of State Road Authorities, 1981).

2.1.2.1 South African National Roads Agency (SANRAL) Specific Requirements

Circular No. 11 of 2017, issued in October 2017, states that single-column piers supporting bridges, with no structural redundancy, must be designed to withstand twice the traffic accident impact loads specified in TMH7. Furthermore, if such piers are particularly vulnerable and lack barrier protection, the design must account for three times the specified impact loads (Ronny, 2017). The following nominal forces have been considered:

1. Horizontal longitudinal force = 9*v kN, in any direction parallel to the direction of the underpassing road. (v = design speed for underpassing roadway in km/h).
2. A horizontal transverse force of 3*120 kN (360 kN) in a direction normal to the direction of the underpassing roadway.

The impact force load combinations are as required by TMH7.

2.1.3 Other International Standards

To support the comparison, the Eurocode and American Association of State Highway and Transportation Officials (AASHTO) standards were included as additional data points and presented in Table 1. This provides context and facilitates a more comprehensive comparison across the various design codes.

Table 1: Impact design loads as per Eurocode and AASHTO

Location	Design Code/Standard	Design Load	
		Perpendicular to direction of traffic	Direction parallel to traffic
Europe	Eurocode BS-EN 1-7 Table 4.1	500 kN (0.5m to 1.5m above level of carriageway or higher)	1000 kN
USA	AASHTO LRFD 3.6.5.2	600 kip = 2669 kN (angle of impact between 0 and 15 degrees)	

2.1.4 Comparison of Pier Impact/Collision Load

The impact load comparison has been undertaken for a vehicle speed = 100 km/h.

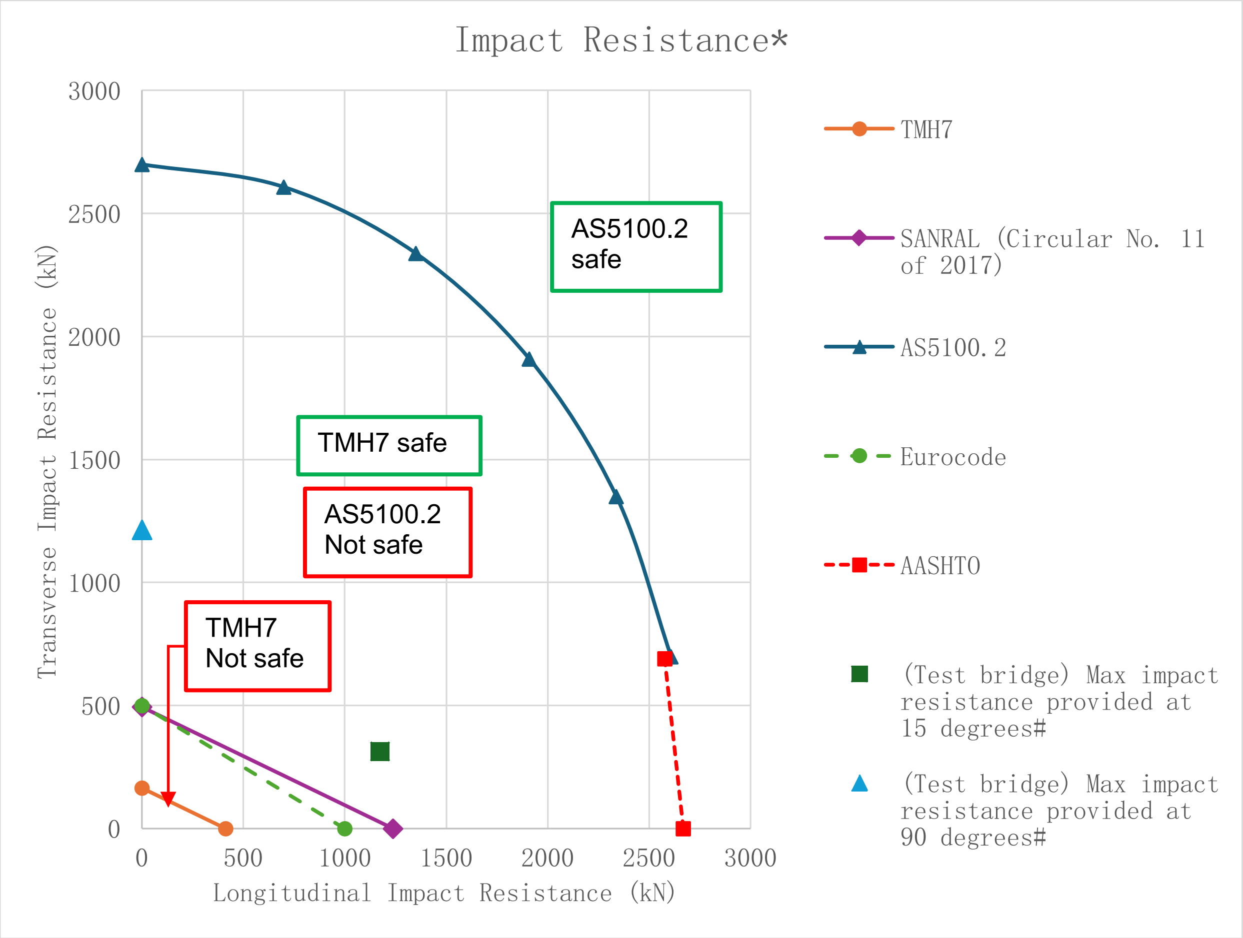
Table 2 provides a summary of the load combinations for AS5100.2 Cl 23 and TMH7 Cl 5. The 2 load factors for dead load and superimposed dead load (SDL) consider reduced and increased safety. The ULS impact load factors specified in the Eurocode and AASHTO are 1.

Table 2: ULS Load combinations (LC) comparison

		Dead Load	SDL	Impact Load
AS5100.2 (ULS)	LC1	1.2	2	1
	LC2	0.85	0.7	
TMH7 (ULS)	LC1	1.32	1.32	1.375
	LC2	1.1	1.1	

An existing bridge, constructed in Queensland, Australia in 1989, was assessed using the methodology outlined in the DCBoS. This bridge served as a case study to illustrate how the various code requirements compare when applied to a real-world structure subjected to impact loads.

The bridge features a 2-span arrangement, simply supported at both the abutments and the pier. The abutments are founded on piles with twin blade piers each founded on its own spread footing. The span lengths are approximately 23 m with a deck width of approximately 12 m. The assessed pier consists of 2 blade piers, spaced 7 m apart, each measuring approximately 1.8 m wide and 0.65 m deep. The piers were evaluated under the 2700 kN impact load applied at an angle of 15 and 90 degrees from the underpass road alignment at 1.2 m above the existing ground level. The minimum angle of 15 degrees is governed by the DCBoS Cl 4.12.13 (Transport and Main Roads, 2024). The maximum longitudinal and transverse impact resistance are presented in Figure 2.



* Impact angle measured relative to underpass road alignment.
# Maximum impact resistance for existing test bridge. Impact angles checked were 15 degrees and 90 degrees to the underpass road alignment.

Figure 2: Graph showing the range of impact forces over varying angles of impact

Impact loads as required by SANRAL, Eurocode and AASHTO were included for comparison. Figure 2 shows that the maximum impact resistance did not meet the loads specified in AS5100.2 (including the DCBoS), and AASHTO. However, if compared to the TMH7, SANRAL and Eurocode, the existing bridge would have sufficient capacity. The impact loads specified by AASHTO and the DCBoS closely align, however, the DCBoS specifies a minimum impact angle of 15 degrees while the AASHTO specifies that the only two angles assessed are 0 and 15 degrees. Piers designed to AS5100.2 will generally have a greater capacity to resist collision loads compared to the other design standards referenced in this paper.

Figure 3 provides a comparison of the calculated impact load for a vehicle with a mass of 50 tons traveling at 100 km/h at an impact angle of 0 degrees, this was compared to the impact loads discussed in section 2. The analysis takes into account the variation in the time taken for the vehicle to decelerate upon impact, illustrating how these factors influence the resulting impact forces and the respective design standards.

The force (F) due to mass of vehicle (m), speed of vehicle (v) and deceleration time (t) was calculated using basic mechanics as follows:

$$F = m.a \; ; \; a = \frac{v}{t} \text{ this yields the following in terms of t - } F = \frac{m \times v}{t} \tag{1}$$

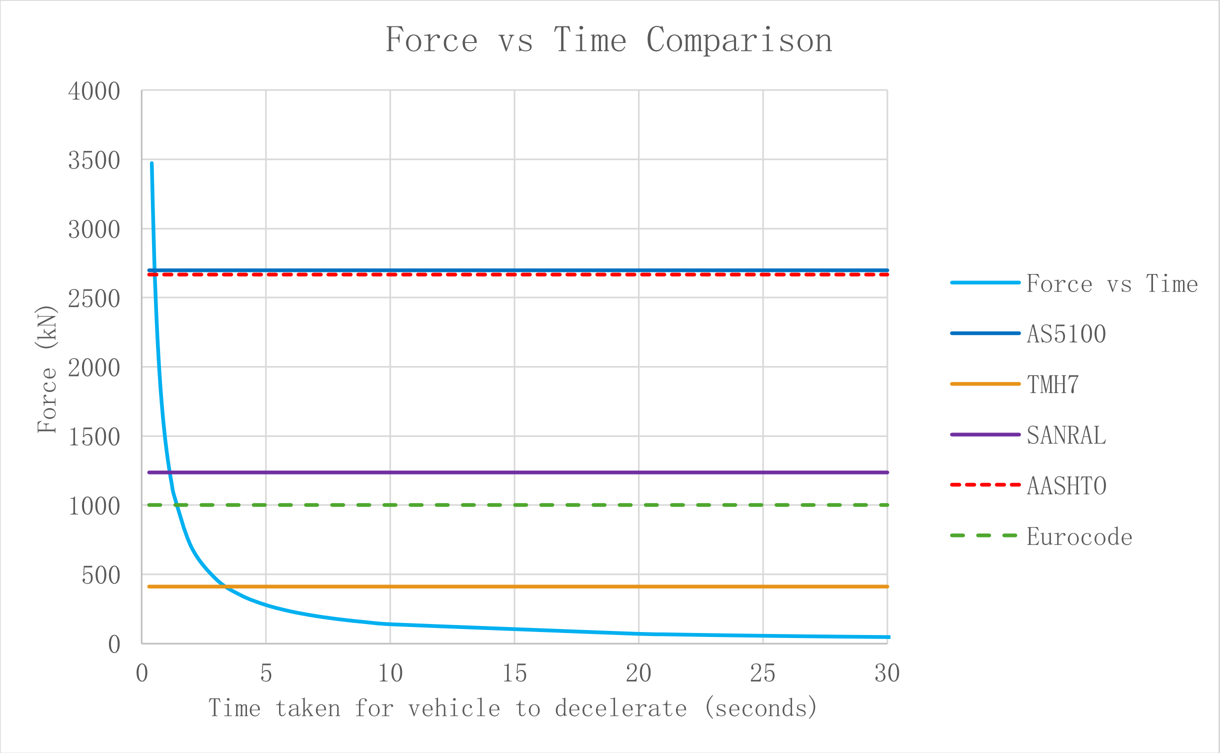


Figure 3: Graph showing the force due to vehicle mass vs the time taken for the vehicle to decelerate

As can be seen from Figure 3, the impact loads specified in TMH7 will only be sufficient for a time to deceleration greater than 3.4 seconds, while AS5100.2 accounts for a vehicle time to deceleration greater than 0.52 seconds. AASHTO aligns closely with AS5100.2. Eurocode and SANRAL will be sufficient for a time to deceleration greater than 1.4 and 1.12 respectively.

2.2 Pier Protection Comparisons

2.2.1 Australian Requirements

The bridge support has to be checked under the loads described in section 2.1, where the structural capacity of the bridge support is not adequate, the bridge support must be strengthened to resist the loads, otherwise pier protection barriers need to be provided and the bridge support isolated to ensure impact loads are not transferred into the piers and foundation. When there are blade piers and/or no structural support redundancies, the DCBoS further limits the use of pier protection barriers and requires the pier to be designed or strengthened to accommodate the impact loads.

2.2.2 South African Requirements

Pier impact load assessments are not required when a rigid barrier is located in front of the pier as per TMH7 Cl 3.7.1 (Committee of State Road Authorities, 1981).

2.2.2.1 SANRAL Requirements

If no barrier protection is provided in front of the pier, the pier has to be designed for three times the TMH7 impact loads instead of two times the TMH7 impact loads (Ronny, 2017).

2.2.3 AASHTO Requirements

AASHTO specifies that barriers used for pier protection shall be Manual for Assessing Safety Hardware (MASH) tested TL-5 rigid concrete barriers, with approximately 990 mm between the traffic face of the barrier and the nearest face of the pier (AASHTO, 2020).

3. BARRIER DESIGN

The primary purpose of traffic barriers is to contain and redirect vehicles. This section discusses the design of bridge barriers in Australia and South Africa. The risk assessment to determine the level of performance is not discussed.

3.1 Australian Requirements

A risk assessment at the bridge site has to be undertaken to identify the barrier performance level required. The performance levels are defined in AS5100.1 and are listed below:

1. No barrier.
2. Low performance level barriers.
3. Regular performance level barriers.
4. Medium performance level barriers.

Height requirements and the design loads for which these barriers must be designed are as per the AS5100.2 Table 12.2.2 and 12.2.3 - summarised in Table 3 and Figure 4 below.

Table 3: Bridge barrier design loading

Barrier performance level	**Ultimate transverse outward load (F_T) (kN)**	**Ultimate longitudinal or transverse inward load (F_L) (kN)**	**Vehicle contact length for transverse load (L_T) and longitudinal load (L_L) (m)**	**Ultimate vertical downward load (F_V) (kN)**	**Vehicle contact length for vertical load (L_V) (m)**	**MASH test level**	**Minimum effective height (mm)**
Low	150	50	1.1	22	5.5	TL2	600
Regular	300	100	1.2	100	6	TL4	900
Medium	600	200	2.4	300	12	TL5	1200

An ULS load factor of 1 shall apply and the load combinations are as follows:

1. Simultaneously apply transverse and longitudinal loads.
2. Vertical loads applied alone.

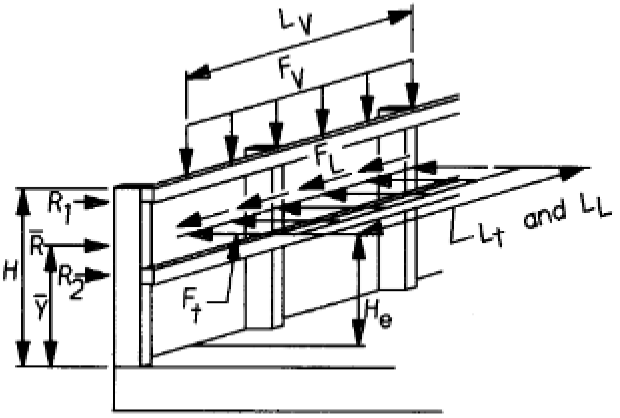


Figure 4: Barrier design load application (AASHTO, 2020, p.13-19)

AS5100.2 Cl 12.3 requires that the design ultimate capacity of the bridge deck shall be a minimum of 1.2 times greater than the design ultimate capacity of the barrier connection to the deck (Standards Australia, 2017). In addition, VicRoads BTN001 Cl 3.3.1 notes that the design of barriers must include provisions to enable an efficient and safe replacement of a damaged barrier, as a result a damaged barrier must not result in any damage to the deck. Therefore, the barriers, barrier connections and supporting systems must be designed as a progressive strength system so that barriers and connections fail prior to the failure of the support system (VicRoads, 2023). Consequently, the deck is designed to be stronger than the connection and the connection is designed to be stronger than the barrier, this results in a high reinforcement rate in the bridge deck.

3.2 South African Requirements

Reference has been made to both TMH7 and the SANRAL requirements. Table 4 summarises the design loads required by TMH7 (Committee of State Road Authorities, 1981) and SANRAL (SANRAL, 2012).

Table 4: Transverse balustrade design loads required by TMH7 and SANRAL

Balustrade Classes	Barrier Design Loads (Transverse load)	
	TMH7	SANRAL
Class 1 (resist impact by vehicles)	50 kN	100 kN (200 kN at critical locations i.e. high accident zones)
Class 2 (contains pedestrians)	15 kN or 4.5 kN/m	NA

When compared to Australia's medium barrier performance requirements, SANRAL specifies an impact load that is approximately six times lower for a similar performance level. Australia's medium barrier performance levels are guided by the AASHTO MASH Test Level 5, which is based on the impact of a 36-ton vehicle traveling at 80 km/h.

There are currently no specific design requirements in South Africa addressing the deck's capacity to withstand balustrade design loads in a way that limits damage to the deck itself. This oversight can hinder the ease of barrier replacement following a significant impact event, as excessive deck damage may require more extensive repairs.

4. FUTURE CONSIDERATIONS

The following topic falls outside the scope of this paper and has, therefore, not been addressed. However, this is an important consideration and should be explored in future research to provide a more comprehensive understanding of the subject matter:

- Dynamic load effects compared to the standard static effects under vehicle collision.

5. CONCLUSION

This paper has assessed and compared bridge pier impact load requirements between South Africa and Australia. To broaden the scope of the comparison and enable a more comprehensive evaluation of international design standards, the Eurocode, AASHTO, and SANRAL's revised requirements were also incorporated. An existing bridge, located in Queensland, Australia, was used as a case study to evaluate structural resilience under impact loads based on different regional standards. This comparison provided insights into how an identical structure performs under different regional design standards.

Additionally, the paper has elaborated on the methodology for barrier design in Australia and compared it to practices in South Africa, highlighting key differences and best practices that contribute to improving safety and resilience in bridge infrastructure across the region.

6. ACKNOWLEDGEMENTS

The work conducted by Zutari; and Zutari's Global Design Centre Bridge and Civil Structures team in South Africa.

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