AMELIORATING MOTORCYCLIST INJURY RISK FROM FLEXIBLE BARRIER COLLISIONS IN VICTORIA

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ABSTRACT

Run-off-road crashes are a major cause of death and serious injury on Australia’s roads. Typically involving roadside objects, such crashes account for over half of all fatalities in regional Victoria. While conventional barriers, such as concrete barriers and steel guardrails, have had only limited success in addressing run-off-road crashes, more recently, flexible barriers used over long lengths of roadway have shown great potential, especially in high-speed settings. European and Victorian experience indicate reductions of up to ninety per cent in serious and fatal injury run-off-road crashes. Flexible barriers deform and re-direct errant vehicles by absorbing a substantial proportion of the kinetic energy at impact, thereby frequently avoiding the severe outcomes generally associated with rollovers or crashes into rigid objects. However, there have been concerns that these barriers pose considerable injury risk to motorcyclists who strike them. In order to address these concerns, while still obtaining the safety benefits for the vast majority of road users, a number of barrier devices with the potential to ameliorate rider injury risk have become available. This paper reviews the main options available and identifies those that may be suitable for trial on Australasian roads.

INTRODUCTION

Wire rope barriers, also known as flexible barriers, have been utilised nationally and internationally to combat run-off-road and head-on crashes for well over a decade. Their proven effectiveness in re-directing vehicles back on to the road, combined with relatively cheap installation costs, provide a strong basis for large-scale use of flexible barriers. Motorcyclists, however, are concerned that aspects of the barriers, in their current form, can be a life-threatening hazard.

Modification measures to barriers that address these concerns have been evaluated to an extent and are in use in several countries. Important opportunities now exist in Victoria to incorporate these modifications within standard practice.

The purpose of this paper is to present and discuss a number of these design modifications currently in use in other countries, and identify measures most suitable for immediate adoption along Victorian roadsides.

BACKGROUND

Extent of Crash Problem

Run-off-road crashes, generally single vehicle crashes (where a vehicle runs off the road, hitting roadside objects, or rolling over) are a major road safety issue. They represent the largest single source of serious road trauma in Victoria, resulting in three to four of every ten fatalities, and, on average, high-severity injuries (Larsson, Candappa & Corben, 2003). Single-vehicle crashes are not specific to Victoria either, as indicated below:

- Australia-wide, single-vehicle crashes accounted for 45% of all fatal crashes between the period 2002-2004 (ATSB 2004);
- In South Australia (2002), 67% of all fatal crashes involved single vehicles (Transport SA, 2002);
- In Queensland in 2002, 46% of fatal crashes were single-vehicle crashes and 24% of hospitalisation outcomes involved hitting an object (Queensland Government, 2002);
- In Western Australia (2000), 36% of fatal crashes involved hitting an object; based on data from the Office of Road Safety, 2000;
- In NSW (2001), 37% of fatal crashes were single-vehicle crashes (Road Traffic Authority NSW, 2001).

Run-off-road crashes are prevalent in both rural and metropolitan regions. Injury consequences though, tend to be more severe in rural areas due to the higher speeds involved. Run-off-road crashes contribute to more than half of all fatalities in rural Victoria (Corben & Johnston, 2004).

Swedish studies have found that single-vehicle crashes are strongly correlated with the traffic volume on the road, with a large proportion of crashes occurring on a small percentage of the total length of road network. Larsson et al. (2003) report that about 80% of the road toll due to single-vehicle crashes can be addressed by focussing on about 40% of the road length. Although further research is required, similar findings are anticipated for the Victorian road network. One study found that "…on just seven routes in Victoria, totalling 673 kilometres in length, there have been a total of 425 serious casualty run-off-road crashes in five years. Crash densities ranged between 0.07 and 0.23 serious casualty crashes per kilometre per year, with the average for the seven key routes being 0.13," (Corben & Johnston, 2004, p.3).

Potential Solution and Effectiveness

Although many countermeasures exist to combat run-off-road crashes, in recent years, flexible barriers have generally produced the greatest reductions in serious and fatal injury run-off-road crashes. Sweden, a world leader in road safety, has over 800 km of flexible barriers on its roads. Some studies in Sweden have reported as much as a 90 per cent reduction in the incidence of serious and fatal injury run-off-road and head-on crashes associated with the installation of flexible barriers (Larsson *et al*., 2003). This reduction is considerably larger than the safety gains associated with other treatment options for run-off-road crashes, including steel guardrail, concrete barriers, sealed shoulders, delineation improvements and clear zones. For example, a range of engineering treatments implemented in Victoria between 1989-1990 and 1993-1994, with the aim of reducing the incidence of collisions into fixed roadside objects, effectively reduced all casualty crashes by less than ten per cent on average and crash costs by around 15 per cent (Corben, Deery, Mullan & Dyte, 1997). Large-scale shoulder sealing, generally accepted as an effective treatment for run-off-road crashes, has produced reductions of around 30% of all casualty crashes. Even the combination of treatments such as shoulder sealing, line marking and removal of hazards resulted in reductions in both crash frequency and casualty costs of approximately 50 per cent (Delaney, Jacques, Corben & Newstead, 2002). This is compared to the reductions of up to 90% achieved through flexible barriers. It should be noted that reductions for flexible barriers generally refer to fatal and serious injury casualty crashes only while reductions quoted for other countermeasures often include all casualty crashes. Nevertheless, even if only serious casualty crashes were considered for the above treatments, the reductions are still likely to fall short of reductions of around 90 per cent effected by flexible barriers.

Barrier Design

Typically manufactured in two basic design forms, flexible barriers have four heavily tensioned steel cables fastened in parallel or criss-crossed between posts to 'catch' out-of-control vehicles that are leaving the roadway (Figure 1). Flexible barriers are also utilised to separate two opposing directions of traffic on undivided roads or along medians to prevent head-on crashes and crashes with trees, poles and other rigid objects located within medians.

The design philosophy for roadside barriers that has developed over many years appears to not take explicit account of the needs of motorcyclists. Roadside barriers are designed to meet established US or European crash-testing standards. These standards define the crash test conditions in terms of vehicle mass, speed and angle of impact, with generally no requirement to consider motorcyclists. As a consequence, the physical design and performance of barriers in collisions with motorcyclists can be insensitive to the specific needs of this highly vulnerable category of road user. Of particular concern, is that the mass of a rider is about an order of magnitude less than a typical vehicle. A barrier post designed to collapse in an impact with a vehicle therefore may prove effectively rigid to a motorcyclist.

Unlike for motorcycles, however, the mass of heavy vehicles appears to not create a significant problem in flexible barrier collisions, with the barriers containing tensile forces much greater than design values (Jacques, Franklyn, Corben & Candappa, 2003).

The high crashworthiness of flexible barriers for vehicle occupants can be attributed mainly to the deformation that occurs upon impact with the highly-tensioned steel cables. The frangible barrier posts are designed to collapse upon impact, releasing the tension from the ropes and guiding the errant vehicle to a gradual standstill on the side of the road. Much of the vehicle's kinetic energy at impact is dissipated during the period of barrier deformation, leaving a substantially reduced amount of kinetic energy to be absorbed by the vehicle and its occupants. The distribution of the corresponding kinetic energy between barrier, vehicle and occupants depends upon several factors. They include, the angle and speed of impact, the crashworthiness of the vehicle, use of in-vehicle restraint systems and physical conditions of the roadside.

The near-total conversion of run-off-road crash consequence from serious injury to minor injury, the ability to restrain even heavy vehicles, along with easy, cost-effective installation procedures, altogether suggest that flexible barriers would be an indispensable, key treatment option for run-off-road crashes in Victoria. Although used in over 25 countries, flexible barrier use in Victoria has been minimal when compared with the opportunities available. Based on Sweden's road network characteristics, indications that only a minor proportion of Victoria's road network needs to be treated in order to address the majority of single-vehicle crashes further highlight the opportunities for flexible barriers to be used extensively throughout Victoria.

Impediments to Large-scale Use

As mentioned previously, flexible barriers, address run-off-road crash consequences for the vast majority of road users through their flexibility. However, they represent a more rigid object for errant motorcyclists. Aspects of the posts and wire cables have also caused significant concern within motorcyclist groups: motorcyclists, fearing the injuries associated with the sharp edges of the barrier posts, and the possibilities of being "sliced" by the wire ropes upon impact, have in the past called for the prohibition of the barriers until further research is undertaken to ascertain injury risk to motorcyclists. These concerns may have influenced the degree of barrier use throughout Victoria.

Figure 1: Typical flexible barrier design

Potential Risk to Motorcyclists

- Motorcycle Involvement in Crashes

Motorcycling, in general, carries a high risk of injury. The Transport Accident Commission (TAC) reports that in Victoria in 2002, motorcyclists represented just 3 per cent of all registered vehicles but were involved in 14 per cent of all fatalities (TAC, 2003). Similarly, motorcyclist travel represents less than 1% of travel on Victorian roads (ABS, 2005), yet accounted for 12% of road deaths in 2004 (ATSB, 2005). Motorcyclists are reportedly 29 times more likely to be fatally injured per 100 million kilometres travelled than other vehicle operators (ATSB, 2002).

- Motorcyclist Involvement in Single-vehicle Crashes/Crashes into Barriers

In NSW in 2001, seven per cent of single-vehicle crashes involved motorcyclists (Road Traffic Authority NSW, 2001) and in Victoria, 41% of motorcyclists killed in 2004 were involved in a single-vehicle crash (TAC, 2005).

Studies indicate a low proportion of motorcycle crashes involving barriers, with 0.2 per cent of motorcycle collisions in 1994 involving a guard fence (Austroads, cited in Mulvihill and Corben, 2004). Current figures of barrier involvement in motorcycle crashes are expected to be considerably higher due to greater extents of barrier installations and an increase in motorcycle registrations. Additionally, it is unclear whether the term "guard fence" refers specifically to steel guard rail (e.g. W-beam cross-section), or barriers in general, the former leading to an underestimate of the size of the problem involving motorcycle collisions with barriers.

Research suggests that, having collided with a barrier, the likelihood of serious injury to the motorcyclist is disproportionately high. For example, in Denmark, 60% of barrier collisions involving a motorcyclist resulted in serious injury (Federation of European Motorcyclists' Associations (FEMA), 2000). These findings, while indicating the potential hazard any barrier presents to a motorcyclist, also demonstrate the vulnerability of a motorcyclist in collisions with any object, as riders do not have the protection of a vehicle body (afforded to car occupants), and therefore, will receive the full force of an impact. It should be noted also that these findings do not distinguish between the types of barriers involved in the crash. Given the relatively recent introduction of flexible barriers along roadsides, it may be that many of the studies in the 1990s refer to collisions with the more rigid barriers.

No directly relevant research is yet available to adequately address the safety risks associated specifically with flexible barriers for motorcyclists. Furthermore, there have been very few reported crashes involving motorcyclists and flexible barriers, making it difficult to definitively assess the risk this barrier type poses to motorcyclists. Although no evidence has been found of motorcyclists being "sliced" by flexible barriers, including in Sweden's comparatively vast experience with flexible barriers, it is generally accepted that both the posts and the wire ropes of the barrier present a safety risk to errant motorcyclists. It is also accepted that the rigid nature of concrete barriers, and the rigid posts and sharp edges of guardrail barriers, also present serious injury risks to errant motorcyclists. The magnitude of these risks relative to the various barrier types, (or the absence of a barrier), however, has been difficult to determine due to a lack of research in this area. While some motorcyclists suggest that the smooth surface of concrete barriers is more motorcyclist-friendly than flexible barriers, not all agree. A senior engineer from the French organisation SETRA[1] associated with barrier design, suggests that the impact forces involved in most concrete barrier collisions are too great to be considered safe for motorcyclists. A French medical expert on road crashes supports this view, believing concrete barriers are no better than metal barriers in reducing injury risk for motorcyclists (FEMA, 2000).

On the other hand, there is compelling evidence on the highly effective performance of flexible barriers in addressing roadside safety in general. Additionally, flexible barriers have several important safety advantages over other barrier types, such as their high energy absorption properties, (Duncan, Corben, Truedsson, and Fitzharris, 2001). The combination of these factors along with the lack of evidence that flexible barriers are inherently more hazardous to motorcyclists when compared to other options, presents an outstanding opportunity to undertake a major new program directed at roadside trauma, including motorcyclist injuries in run-off-road crashes. Such a program would involve the large-scale installation of flexible barriers to address the overall problem of run-off-road crashes, while concurrently evaluating and developing motorcyclist-friendly devices.

MOTORCYCLIST-FRIENDLY DEVICES

Motorcyclist-friendly devices are intended to minimise injury risk to motorcyclists in barrier collisions. Summarised below are brief descriptions of currently available devices with results of any evaluations reported. The motorcyclist-friendly devices have only recently been introduced and so findings are based on comparatively limited data.

Figure 2 - example of Moto.Tub on site

Moto.Tub

Moto.Tub is intended to protect errant motorcyclists from making contact with the posts, as well as from sliding in between the barrier posts. Developed by Sodirel in France, it comprises two end support units, a rear-clamping device, and two tubular rails that are sleeved into the support piece (Figure 2). Installation and maintenance of Moto.Tub is reportedly fast and efficient. It requires only one person to

[1] SETRA - Service d'Etude Technique Routier et Autotroutier

install the tubing and takes only minutes to assemble each end support. The barrier need not be removed for installation and there are no requirements for specialised tools. The device has been trialled in France in 197 locations over a five-year period between 2000-2004. Evaluation of Moto.Tub is in progress, and includes a series of impact tests conducted at LIER2 in France in which an "instrumented" dummy was projected against a barrier at a speed of 60 km/h, an angle of 30 degrees and in two positions. Sodirel advises that the five-year trial appears to have been successful. In France it is now compulsory to install Moto.Tub on barriers for all new road infrastructure (Le Ministre de l'Equipement, 1999, cited in Hansen, 2004) and on sections identified as posing a high-risk, for existing infrastructure.

Barrier Post Cross-sections

Original flexible barrier design incorporated 'I' posts that have sharp edges exposed, a potential hazard for motorcyclists making contact with them. The more recent "Sigma", C, or S-shaped posts have rounded edges and are considered more forgiving in motorcyclist impacts (Schmidt, 1984; Ellmers, 1997, Koch & Brendicke, 1988, cited in Mulvihill & Corben, 2004). Evaluations on replacing the commonly used 'I' post with Sigma posts (Figure 3), indicate that collisions with Sigma-posts cause only bruising while collision with 'I' posts resulted in fractures and amputations (Ellmers 1994, cited in FEMA, 2000). Sigma posts (or S or C-shaped alternatives) are now integrated into all standard barrier design in Victoria irrespective of barrier location (Thompson, B., 2005).

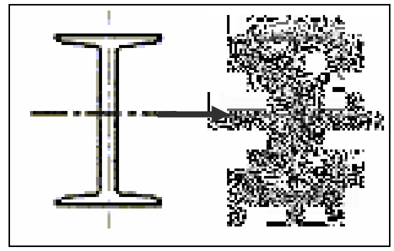


Figure 3 - diagram of I-post (left) and Sigma post

Crash Barrier Post Protectors

Crash barrier post protectors are energy-absorbing encasements fitted onto posts (Figure 4). They are made of polystyrene or similar materials, are durable, and have a life of four years. Evaluations indicate that where crashes have already occurred, post protectors can cut motorcycle fatalities by 25% and substantially reduce crash severity (Mulvihill & Corben, 2004). Trials show that without protectors, resultant injuries are regarded as 'severe'. With protectors, injuries are regarded as 'moderate' to 'minor', and impact deceleration and forces are halved. At present, there have been no real-world incidents of motorcyclists impacting a barrier post protector.

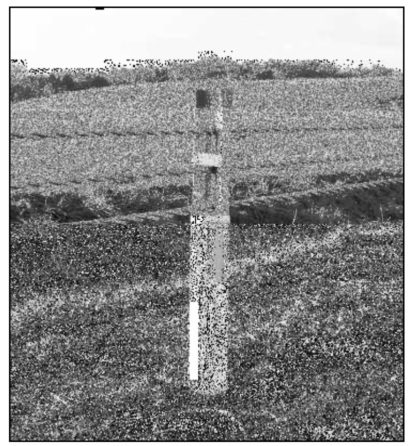


Figure 4 - example of crash barrier post protector

Shrubs as Decelerators

Shrubs, such as the commonly used Rosa Multiflora Japonica, (Figure 5) placed in front of barriers can act as 'speed-breakers' for motorcyclists prior to barrier impact. Some initial evaluations indicate success in decelerating the motorcyclist. Used in a number of countries including Australia, and the US (for a median barrier), barrier-side shrubs are encouraging in reference to decelerating a rider, though they appear to have little effect on an errant vehicle. Research in France indicates that a screen or shroud could be an effective way of reducing motorcycle

Figure 5 - Rosa Multiflora Japonica

[2] LIER - Laboratoire Inrets Equipements de la Route

fatalities (Mulvihill & Corben, 2004). Little or no testing has been undertaken to ensure contact with the thorns is at tolerable levels and that there are no adverse effects of the shrub on barrier performance in passenger vehicle collisions. A disadvantage of the shrub is that, although used in a number of countries, including the US as a median barrier, it is now regarded as a noxious weed due to its dense growth, and could also create maintenance difficulties. An aesthetic benefit to the use of shrubs as decelerators is the concealment of the roadside barriers.

The findings reviewed here suggest that the various forms of barrier post protection and post design modification can have a valuable effect on reducing impact severity for motorcyclists in barrier collisions. Depending on the actual test performed, results show Abbreviated Injury Scale (AIS) (Copes, Sacco, Champion & Bain, 1989) values are often halved; injuries can be converted from severe to minor injuries; and deceleration and impact forces are reduced (Mulvihill & Corben, 2004). The tests however, often do not distinguish between the types of barrier being tested or whether only the post with its protection was included in the test. Products such as aluminium profiling and wire rope covers can be placed over the ropes of the flexible barrier to allay fears of "cheese-cutter" effects. No evaluation of the products had been undertaken at time of writing and so these products have not been presented in the paper for further discussion. Although MotoRail and RubRail, (flat rails that are placed across the barrier posts) are forms of post protectors, they have not been presented here as potential barrier protectors as they are more suitable for steel guardrails.

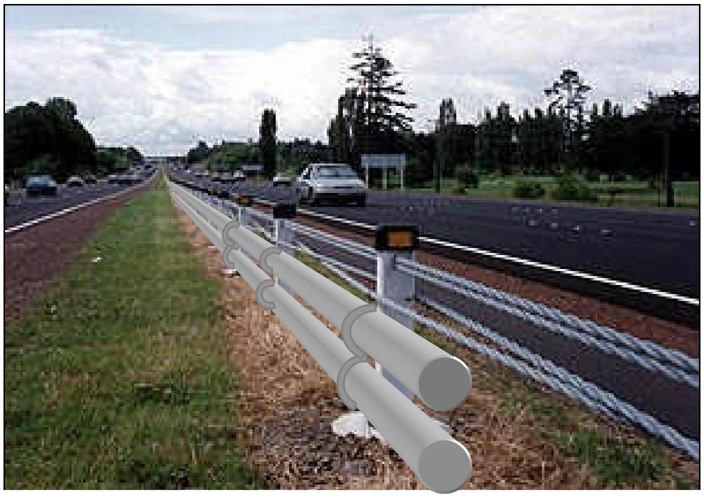
POSSIBLE OPTIONS FOR VICTORIAN ROADS

Given the available information on the effectiveness of the various forms of barrier post protection, it appears that Moto.Tub, Crash Barrier Post Protectors, modified posts and shrub speed-breakers are the measures most readily available for immediate use. The more forgiving Sigma posts, however, are already being used by Victorian and some international road authorities, while shrub decelerators do not necessarily prevent direct contact with the posts. Moto.Tub and Crash Barrier Post Protectors therefore, are currently the two most promising countermeasures for motorcycle injury resulting from barrier impacts. The features of each of these are compared in greater depth below.

Moto.Tub vs Crash Barrier Post Protectors

Moto.Tub and Crash Barrier Post Protectors both absorb impact energy, thereby reducing crash severity, and physically separate the motorcyclist from the post. They are also considered easy to install, and can be incorporated into standard design. An advantage of Moto.Tub in comparison to Crash Barrier Post Protectors is that its longitudinal design could help prevent the motorcyclist from slipping underneath the wire ropes and into a roadside hazard. This helps address motorcyclist concern that wire rope barriers do not fully prevent motorcyclist contact with roadside hazards. It is also possible that the use of recycled material, and Moto.Tub's less intricate design could help keep production costs down, though more formal costing would be required to confirm this.

There are two foreseeable disadvantages of Moto.Tub. Firstly, its longitudinal design could potentially modify the original flexible barrier design more significantly than Crash Barrier Post Protectors (Figure 6). However, no data are available on any adverse effects of the barrier protectors on the restraining capacity of wire rope barriers for passenger vehicles. Secondly, in some cases, a motorcyclist impacting with Moto.Tub could be directed subsequently into the wire ropes themselves. Further research is needed to investigate these two potential disadvantages.



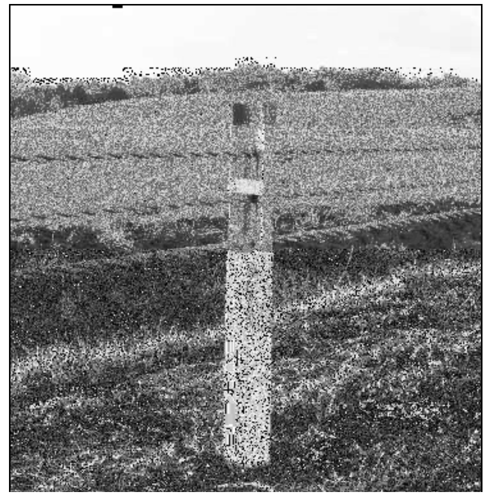


Figure 6: Computerised image of potential use of Moto.Tub on wire rope barriers; and a photo of an on-site Crash Barrier Post Protector (Source: Blue Systems website)

Crash Barrier Post Protectors, on the other hand, seem unlikely to reduce the frangible nature of the posts in vehicle collisions based on typical impact speeds. However, they do not have the advantage of offering protection to errant motorcyclists sliding towards a hazard in between posts.

As there is no clear evidence to endorse one measure over the other, it is recommended that trials of both options be undertaken to better determine the most suitable measure for Victorian road conditions.

Application Potential

In early 2004, there were approximately 100 km of flexible barrier on Victorian roads (Thompson, B., 2004) and this is expected to rise sharply in the coming years. Although sites trialling potential countermeasures are expected in the near future, at present, no barrier protecting devices have been introduced (Thompson, B., 2005). Retrofitting treatments is typically more expensive than including them at construction. Given flexible barrier use in Victoria is still in its early stages, immediate consideration to further study the benefits of the suggested motorcyclist-friendly devices, and adopt a policy on their use, can assist in providing the full benefits of early introduction.

Incorporating barrier protectors on all lengths of flexible barrier will not be economically feasible in the short term given the small proportion of road users who are motorcyclists and the even smaller proportion of crashes where motorcyclist collide with a barrier. Selected use of the barrier protectors will best address motorcyclist concerns while maintaining the viability of the treatment.

Relying on crash history or “BlackSpot” sites to select potential sites for barrier protectors may not be very effective, as run-off-road crashes for passenger vehicles and motorcyclists alike, tend to occur somewhat randomly. However, certain road sections have been identified by motorcyclist groups as posing elevated risks to motorcyclists; namely, motorways and dual carriageways with outside curve radii of less than 400 m, other roadways with radii of less than 250 m, and grade-separated intersections (Hansen, 2004). These sections could be fitted with barriers, irrespective of crash history.

Implementation
Use of barrier protectors on a large scale may yet be difficult to justify since there is no great certainty of their effectiveness. Existing research into the area is limited, inadequate numbers of tests have been undertaken to confirm the effectiveness of post protectors, and insufficient real-world barrier collisions have occurred to substantiate predicted outcomes. Preliminary data overseas are indicative of improved safety for motorcyclists, and demonstrate ease of integration into standard wire rope barrier design. However, there is currently heavy reliance on international, especially European, initiatives to evaluate these devices, resulting in further difficulty in justifying large expenditure without a high likelihood of safety benefits. Therefore, further studies and trial implementation of post protectors in Victoria are essential to rapidly progress the utilisation of motorcyclist-friendly devices. The ultimate aim would be to have them included as part of standard design of wire rope barriers along areas of elevated risk.

CONCLUSIONS/RECOMMENDATIONS

Available research on motorcyclist-friendly devices is limited: real-world collisions in Victoria are scarce, and evaluations of these devices have been mainly undertaken overseas. Moreover, definitions of barrier types in study reports have often been ambiguous, with clear distinctions often not being made between flexible barrier types and their more rigid counterparts. These factors all create difficulty in accurately ascertaining the true effectiveness of the devices presented in this paper. Notwithstanding these limitations, it appears that Moto.Tub and Crash Barrier Post Protectors are currently two devices that can quite readily be integrated into barrier design to help alleviate motorcyclist injury risk in flexible barrier collisions, as well as motorcyclist safety concerns. Further research, and trial sites are essential however to verify the international findings on reductions in injury level, while also ensuring that barrier performance and, in particular, the effectiveness of wire rope barriers is not diminished for the majority of road users. While addressing the concern of injury through post contact, it is important to ensure that the motorcyclist-friendly devices do not create other adverse effects such as redirecting motorcyclists up onto the wire ropes. Trial plantations of shrub decelerators along barriers where road reserve width allows, would help determine their possible benefits to errant motorcyclists. An Australian substitute for the Rosa Multiflora Japonica could be sought to address the noxious weed disadvantage, minimise costs, encourage the use of native plants, and ensure ease of care.

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