World's Best Practice in the Use of Flexible Barrier Systems Along High-Speed Roads

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Biography

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Abstract

Run-off-road crashes represent, arguably, the largest single source of serious road trauma in Victoria and contribute significantly to the road toll in all states of Australia. In recent years, run-off-road crashes accounted for three to four of every ten fatalities, occurring both in metropolitan and rural Victoria. Single-vehicle crashes, on average, produce injuries of high severity due to the involvement of rigid roadside objects. Conventional treatments such as shoulder sealing, delineation and clear zones have had only limited success in reducing the extent and severity of run-off-road crashes. Such treatments tend to result in incremental improvements in safety rather than fundamental changes to injury and crash risks. More recently, flexible barriers (specifically Wire Rope Safety Barriers) have been used over long lengths of roadway, with great success. Flexible barriers deform and re-direct errant vehicles by absorbing the impact energy, thereby avoiding the severe outcomes associated with head-on collisions, crashes into rigid objects or rollovers. Although flexible barriers have already been installed at some sites, their use in Victoria is still in the early stages. Sweden, a world leader in road safety, has used flexible barriers to reduce the occurrence of fatalities on treated routes by up to 90%. This has been achieved through extensive use of flexible barriers and the introduction of the innovative "2+1" road configuration. Under this layout, flexible barriers are positioned along a three-lane undivided road providing alternate sections of two lanes in one direction, separated from the one lane in the opposing direction. Swedish research and practice indicate that a large number of crashes occur on a small percentage of the road network, implying that flexible barriers need only be installed on a minor proportion of the road network in order to effect a large reduction in the road toll. Flexible barriers, therefore, appear to offer a cost-effective and viable solution to this major source of road trauma. Public support for the barriers rose dramatically in Sweden within the first year of implementation. This research-based paper presents findings of world's best practice in flexible barrier use and reports on opportunities to apply, in principle, the flexible barrier treatments employed in Sweden, along Victorian roads, in an attempt to substantially reduce the number of severe run-off-road and head-on crashes.

1. INTRODUCTION

Run-off-road crashes represent, arguably, the largest single source of serious road trauma. In recent years, run-off-road crashes (ROR) accounted for three to four of every ten fatalities on Victorian roads. By 2002, 43% of deaths on Victorian roads involved single-vehicle crashes. A less frequent, yet very severe crash type, especially in high-speed settings, is the head-on crash. In rural areas, head-on crashes on undivided roads are a serious concern. Outstanding early success has been experienced in Swedish trials of the use of flexible barriers on undivided

roads. Due to similarities in road configurations and traffic volumes between Australia and Sweden, the feasibility of applying Swedish principles along Victorian roads was assessed.

2. PROJECT OBJECTIVES AND METHOD

The purpose of this project was to investigate and assess opportunities to address the major source of serious road trauma by ROR and head-on crashes in high-speed settings, through conventional and/or innovative forms of flexible barrier use, drawing upon both Swedish experience and previous studies in this field. This current study notes the general findings from past studies and attempts to move a step further by presenting this treatment option with respect to the various issues that need to be considered if flexible barriers are to be used over extended lengths of high-speed roads in Victoria.

2.1 Definition

"ROR" and "single-vehicle" crashes generally refer to vehicles unintentionally leaving the road pavement to the left or right, including onto the median. Other crash types may have been included in the definition "ROR crashes" in previous studies, without affecting overall conclusions. Although only one form of flexible barrier, Wire Rope Safety Barriers have been referred to as flexible barriers in this study.

2.2 Crash Analysis

Important findings from previous studies into ROR crashes in Victoria are summarised below. It is to be noted that causes of run-off-road crashes have not been evaluated, as the purpose of this treatment is to reduce crash severity making the cause of a crash less relevant.

- ROR crashes are a significant problem in both metropolitan Melbourne and rural Victoria although in rural areas, there is a greater proportion of these crashes. Victoria-wide, between 1996 and 2000, 16 to 19% of all casualty crashes involved fixed roadside objects (Delaney, Langford, Corben, Newstead, & Jacques, 2002) and 60% of all run-off-road crashes involve a roadside hazard (Szwed, 2002). This trend appears to be rising despite recent and current efforts to address it.
- The most common types of ROR crashes involve vehicles leaving the straight section of the carriageway to the left or to the right into objects. Head-on collisions are also quite common as are vehicles running off curves.
- ROR crashes typically result in injuries of above-average severity, with "arrive alive!" Strategy 2002 noting that 91% of fatal ROR crashes in 2000 involved fixed roadside objects.
- ROR crashes generally occur on roads with speed limits of either 100+ km/hr or 60 km/hr. In regional Victoria, 73% of run-off-road-left crashes occurred in 100 km/hr zones, while 57% of metropolitan run-off-road-left crashes occurred in 60 km/hr zones. Of collisions involving fixed roadside objects in regional Victoria, 67% occurred on roads with speed limits of 100 km/hr, followed by approximately 20% of collisions on roads with 60 km/hr speed limits (Delaney et al., 2002).
- Cars (and car derivatives) are generally the most frequently involved vehicle type in ROR crashes, with heavy vehicles involved in up to 10% and motorcyclists represent up to 11% of ROR reported casualty crashes. In 2001, motorcyclists contributed to 14% of overall fatalities, although they represent less than 1% of travel on Victorian roads (Transport Accident Commission). The ATSB (Australian Transport Safety Bureau) found that there is an approximate 30-fold higher risk of a motorcycle rider being killed than of other vehicle operators (per 100 million kilometres travelled, 1998 - 2000).

- In regional Victoria, costs associated with collisions with fixed roadside objects account for over one-third of total average costs of all casualty crashes (Delaney et al., 2002).

3. CURRENT COUNTERMEASURES

There are three main forms of countermeasures in use in Victoria that aim to address the issue of ROR crashes - clear zones, shoulder sealing with delineation, and concrete and guardrail barriers. These have had only limited success in reducing the extent and severity of ROR crashes: a range of engineering treatments implemented in Victoria between 1989/90 and 1993/94 to address the incidence of collisions into fixed roadside objects, were found to have reduced all casualty crash frequency by only 8.6% overall, and crash costs by 15.5% (Corben, Deery, Mullan, & Dyte, 1997).

A. Sweden's Approach to Run-off-road Crashes

Sweden, a world leader in road safety, has utilised flexible barriers to reduce dramatically fatal and serious injury crashes for the target crash types on treated routes by as much as 90% (Corben et al., 2001). This has been achieved by erecting extended lengths of flexible barriers, often in the innovative "2+1" road configuration.

In Sweden, ROR and head-on crashes are major safety issues on rural, two-lane, undivided roads, where two-thirds of all traffic fatalities occur. ROR crashes often have serious outcomes, accounting for more than one third of all traffic fatalities in Sweden. Around three-quarters of all fatal, single-vehicle crashes occur on the Swedish rural road network, with head-on and ROR crashes heavily correlated with traffic volumes. That is, these crash types are highly concentrated on a small proportion of government roads - around 80% of fatal ROR crashes can be addressed by focussing on some 40% of road length, while to address 80% of fatal, head-on crashes, just 15% of the road network needs treatment. (Bergh, Carlsson and Larsson, 2002).

Motorcycle Involvement

Swedish data indicate that between 1997 and 1998, 46% of motorcycle crashes involved side impact collisions, and of these, 13% involved collisions with roadside barriers such as guardrail and flexible barrier.

Implemented Treatments in Sweden

2+1 Concept

As noted earlier, a large proportion of head-on and ROR crashes occur along rural roads in Sweden, with high concentrations on the many kilometres of undivided, 13 m roads. This situation has led to the development of the 2+1 form of barrier treatment. The 2+1 concept has one continuous lane in each direction and one middle lane alternating the permitted direction of travel at intervals of 1.5-2.5 km (See Figure 1). The length of the interval depends on factors such as road alignment and locations of intersections. On-coming traffic is separated by a flexible mid-barrier, preferably within the existing width of 13 m (denoted as 13: 2+1cb).

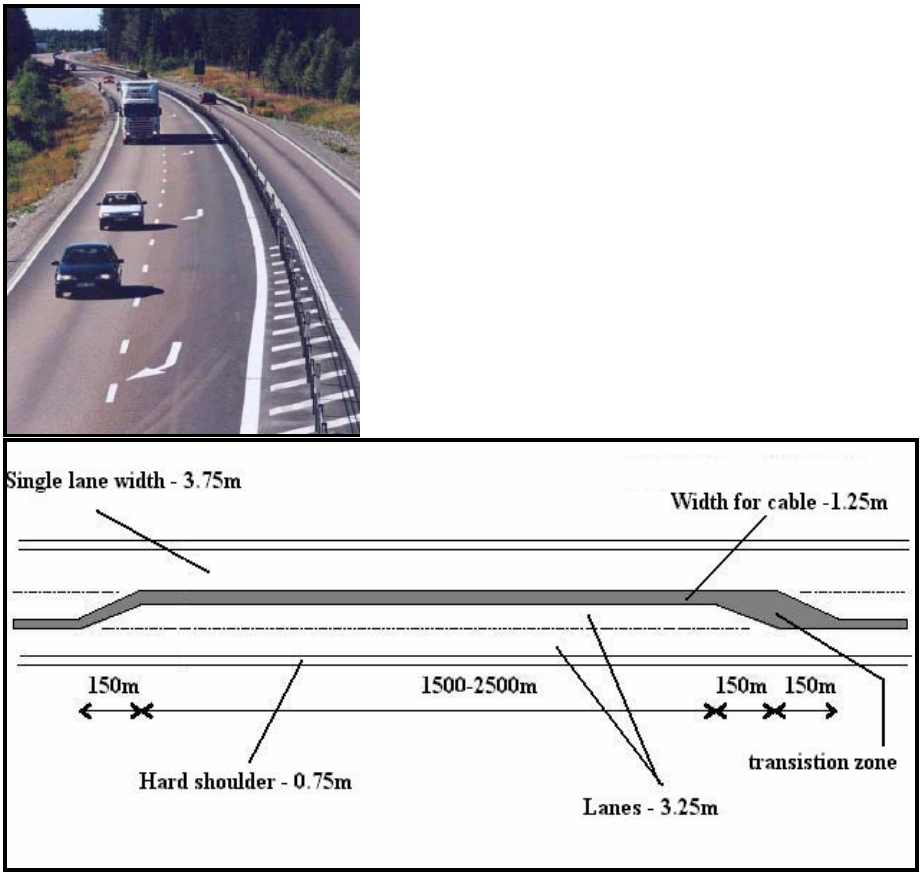

Figure 1: existing 2+1 road in Sweden with diagram of concept details (photo: NCHRP, 2003)

Permitted speed limits on roads modified to the 2+1 format are not affected as a result of the treatment, ranging up to 110 km/hr. The roadsides ideally would be cleared or side barriers erected. The 1+1 and 2+2 concepts are variations of the 2+1 concept, and are used in situations such as on bridges where any widening would be costly and so there can be one lane only each way; and on other roads where restricting traffic to one lane due to volumes is considered impractical. Transition zones from two lanes to one lane in the 2+1 concept are 150 m in length; double-sided signs inform the commuter of approaching lane-closure 400 m ahead of the actual merge, and at the commencement of the transition zone. Transition zones from one to two lanes are 100 m long. Cable poles erected ten metres apart along the transition zone are fitted with delineators. “Quick-locks” create openings in the flexible barriers situated in transition zones.

Results of Barrier-Use in Sweden

In total, approximately 670 km of roadway was operational in 2002, 630 km operating as 2+1 roads with flexible barriers separating opposing directions of travel.

Crash Reduction: As a result of the implemented treatment, the incidence of fatalities on treated routes has currently decreased by up to 90% on semi-motorways that have had a comprehensive flexible barrier system installed (both along the median and roadsides) and by up to 76% on regular single-carriageway 13 m roads converted to a 2+1 cross-section with barriers. To date, although there have been three deaths on 2+1 roads, the causes were not as a result of the installation of flexible barriers. Collisions with flexible barriers along the centre of the road can be very frequent, with around one mid-barrier crash per week (NCHRP, 2003) but normally without injury to vehicle occupants.

Capacity: Traffic capacity is noted to have decreased with the implementation of this treatment. The capacity in one direction, is estimated to be about 1550 veh/hr (on 90 km/hr speed zones) and 1500 veh/hr (on 110 km/hr speed zones), some 400-450 veh/hr less than for an ordinary 13 m road. The lane-drop transitions have performed well, drivers in the transition area being cautious and responsible (NCHRP, 2003).

Level of Service: The level-of-service on 2+1 roads has been better than expected. Floating car studies confirm a good level of service at traffic flows up to 1,300-1,400 veh/hr in one direction (NCHRP, 2003).

Speed: Speed performance on 2+1 roads has remained largely unchanged.

Work Zone Safety: Work zone safety is a major concern. Repairs have so far been conducted using a Truck Mounted Attenuator (TMA), closing the overtaking lane and providing only one lane for each traffic direction.

Emergency Access: Permanent emergency openings in the flexible barriers are established every 3-5 km to allow rescue vehicles to U-turn. Ideally, the number of access roads should be minimised, and pedestrians and cyclists should be separated from other traffic where it is possible to do so at reasonable cost.

Public Opinion - Driver Attitudes: Although initially wary, general survey results indicate that about 80% of those surveyed say that they want all major roads to have median barriers.

Motorcycle Crashes: No evidence has been found in Swedish experience to indicate that flexible barriers are particularly hazardous to motorcyclists when compared with other forms of barriers.

Costs: Costs for the installation of flexible barriers on freeways, including all necessary modifications to the existing road format, are estimated at AUD$250/m, with 21% of the total costs for flexible barriers. On 13m single-carriageway roads, it costs AUD$380/m to convert the roads into 2+1 formats, flexible barrier costs accounting for 16% of total costs. Maintenance costs have increased, costing about AUD$23,000 per km per year with AUD$15,000 (65%) of this for cable repairs.

B. Victorian Roads

Having established application and effectiveness of flexible barriers in Sweden, an important opportunity exists to determine how successfully similar principles could be applied along Victoria's, and indeed Australia's, roads. Actual and predicted results are summarised below for the three main categories of roads in Victoria: four-lane divided and undivided and two-lane undivided.

Proposed Treatment:

- For four-lane divided and undivided road formats, barriers should be placed continuously along either side of the median for divided roadways and along the centre of the road for single-carriageway roads, with barriers along the sides of the roadway as well. This provides the highest level of road performance according to crashworthiness.
- For two-lane undivided roads, providing continuous barriers along the centre and sides of the road will also provide the highest level of road performance according to crashworthiness. There will be some minor reductions in lane widths, significant reductions in shoulder widths and some

widening to create a third lane. Reduced shoulder width adjacent to flexible side barriers can be expected to adequately address serious injury risk for the occupants of errant vehicles. However, an extra one-metre strip of road with full load-bearing capacity can be provided along the one-lane sections of these roads for breakdowns. High-speed roads often have existing 2.5 to 3 m shoulders and wide road reservations. The 1+1 format can be used on bridges and road sections that are expensive to widen, and on sections with many access roads, or pedestrians and cyclists, where separation is costly or impractical.

Crash Reduction:

- On four-lane divided and undivided roads, it is anticipated that fatalities will be reduced by up to 90%, converting single-vehicle crashes with possibly high levels of injury to crashes against the barrier with, in many cases, slight or no injuries.
- Two-lane undivided roads are expected to experience reductions in fatalities of up to 76%.

Cost-Effectiveness: Inadequate data are available to reach conclusive results on the cost-effectiveness of flexible barriers. However, an indicative study of the benefits expected on three major metropolitan freeways from the use of flexible barriers along medians, found that even at a very conservative cost of $130/m, flexible barriers are a highly cost-effective solution (Corben et al., 2001). Unit costs of installation should reduce as barrier-use is implemented on a wider scale, thereby making Benefit-Cost Ratios even more attractive. Further research is required to determine the proportion of crashes occurring on Victoria's road network although it is anticipated that as in Sweden, a large proportion of crashes will occur on a small percentage of the road network, thereby increasing the cost-effectiveness of the treatment. Sweden is currently undertaking a study on cost-effectiveness of flexible barriers in Sweden.

Speed: Although somewhat counter-intuitive given the narrowing of lane widths, vehicle speeds are predicted to remain virtually the same for all road formats.

Traffic Operations:

- On the four-lane divided and undivided roads, there should be no change to the traffic operations, as the road configuration will not be significantly modified.
- On the two-lane undivided, traffic capacity is about 1550 veh/hr (on 90 km/hr roads) and 1500 veh/hr (on 110 km/hr roads) in one direction, approximately 400-450 veh/hr less than for an ordinary 13 m road.

Appropriate response rates for the removal of vehicle breakdowns would need to be addressed to ensure a broken down vehicle on the single lane will not greatly reduce the capacity of the lane.

Emergency Access/Property Access: Emergency access points should be created along the barrier every 3-5 km. Access roads to properties on highways and two-lane roads ideally should be minimised; and pedestrians and cyclists separated where possible at reasonable costs.

Environmental: The general concept of 2+1 barriers can be advantageous environmentally, as trees and other environmentally significant objects can remain in medians and within roadsides, provided they are outside the barrier's working width. Land acquisition required for road widening is also reduced.

Heavy Vehicles: Though not designed specifically for heavy vehicle impacts, flexible barriers have been found, in both real-world and crash-tests, to successfully restrain a heavy vehicle; flexible barrier tensile strength has been reported to be four times greater than W-Beam guardrail

(Working Party Report, 2000). It should be noted however that large deflections of up to 4 m have been recorded in collisions involving heavy vehicles.

Public Opinion:

- Treatments for the four-lane roads are unlikely to create great concern for the public, as they do not alter the format of the road greatly and so the usual conditions are generally maintained.
- Changing the two-lane undivided road design to the 2+1 concept will most likely generate concern, at least initially, among some motorists. It is important therefore to launch an information campaign to inform the public of the benefits by the design concept. Motorcyclists will likely be concerned and therefore should be invited to take part in the development of barrier-use initiatives along high-speed roads in Victoria.

Maintenance: Although the maintenance requirements of the flexible barriers may be greater than for more rigid barriers due to increased minor impacts by vehicles, the maintenance is considered relatively inexpensive and quick, one barrier manufacturer reporting that damage to four posts in an impact was repaired and checked in around nine minutes (Schmidt, 2000). Flexible barriers left in a state of disrepair can leave road-users exposed to this hazard, and therefore a policy regarding the appropriate response time for repair needs to be addressed. Indicative maintenance costs are estimated at $50/m for flexible barriers; $80-100/m for W-beam steel barriers and no maintenance is undertaken of concrete barriers (Working Party Report, 2000). Work-zone area safety is a major concern. Repair work may require the use of TMAs, temporary closure of the overtaking lane, with all traffic using one lane for both directions. Details of safe practice for the workers need to be determined. There is some concern with emergency blockages and emergency vehicle operation that can be solved in cooperation with emergency services.

4. DISCUSSION - IMPROVING SAFETY ON VICTORIAN ROADS

Based on Swedish experience, some 40% of Victoria's serious road trauma could be addressed, and overall safety improved for the vast majority of users on treated routes, by installing median and side barriers as a standard solution, starting on roads with the highest traffic volumes.

Victorian studies of the then proposed installation of flexible barriers along major urban or inter-urban freeways suggested flexible barriers could dramatically cut road trauma (Duncan, Corben, Truedsson and Fitzharris, 2001). This is supported by data obtained from a limited number of sites in Victoria where flexible barriers have been installed; an estimated 92% reduction in run-off-road casualty crashes was calculated over an 18-year period (Szwed, 2002). It should be noted that these are evaluations of flexible barriers only and not strictly comparable to the 2+1 barrier systems in Sweden; the road layout itself however is not expected to contribute significantly to crash reductions making the findings still relevant.

Duncan et al (2001) addresses concerns associated with crash-involved motorcyclists, finding that motorcycle impacts into flexible barriers had been extremely infrequent to that time. The question arose as to whether it is ethically responsible to deny the vast majority of vehicle-based road users (i.e., non-riders) the high safety gains possible from flexible barriers compared with other barrier types. To resolve these technical and ethical concerns, it was proposed that road authorities continue to use flexible barriers where they maximise safety benefits to the majority of road users. Further, it was recommended that, wherever possible, flexible barriers should be installed with the maximum practical distance between road and barrier to give all road users (especially motorcyclists) the greatest opportunity to either regain vehicle control or shed speed

prior to impact. Timely maintenance of flexible barriers and avoidance of unwarranted usage and inappropriate placement of any barrier type were also recommended.

It was acknowledged that insufficient knowledge exists on the interaction between motorcyclists and roadside barriers, as well as on issues regarding access along rural roads and broken down vehicles. Further research and development work is needed to improve barrier performance for all road users and to ensure smooth large-scale barrier-system implementation along Victorian roads.

5. CONCLUSIONS

Given the large overall reductions in serious casualty crashes found and predicted, it is recommended that, where suitable, road designers consider flexible barriers the preferred treatment option along roads that account for a substantial part of roadside trauma. Evaluation of data at these sites can also be undertaken to review and improve road infrastructure design standards of the future Concurrent to its use, however, research needs to be undertaken to improve barrier designs, especially for motorcyclists. Trials of the suggested treatment concepts at various sites are also essential to confirm overseas experience.

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