Guide to Road Design Part 6

Roadside Design, Safety and Barriers

Austroads

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Austroads

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Guide to Road Design Part 6: Roadside Design, Safety and Barriers

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Abstract

The *Guide to Road Design Part 6: Roadside Design, Safety and Barriers* provides an introduction to roadside design and in particular guidance on roadside safety and the selection and use of road safety barrier systems.

Roadsides have to accommodate many features that support the road and the safe and efficient operation of traffic and have to be designed with regard to environmental requirements. Part 6 should therefore be read in conjunction with the following parts of the Guide to Road Design that are briefly described in Section 2 of this guide, namely:

- Part 6A: Pedestrian and Cyclist Paths
- Part 6B: Roadside Environment.

Part 6 provides information to enable designers to understand principles that lead to the design of safe roads, identify hazards, undertake a risk assessment process of roadside hazards, establish the need for treatment of hazards and determine the most appropriate treatment to mitigate hazards.

Methods of evaluating roadside hazards and the effectiveness of treatment options are summarised and references are provided for detailed information on project evaluation. A comprehensive design process, guidance and design considerations are provided for the selection of a suitable road safety barrier and for the lateral and longitudinal placement of road safety barrier systems.

Keywords

roadside design, designing for safety, hazard, hazard identification, risk assessment, clear zone, hazard mitigation, treatment options, evaluation, road safety barrier systems, road safety barrier design process, deflection width, medians, containment level, working width, run-out length, angle of departure, points of need, terminal treatments, transitions, vulnerable road users, steep downgrades, arrester beds, barriers at intersections

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About Austroads

Austroads is the peak organisation of Australasian road transport and traffic agencies.

Austroads' purpose is to support our member organisations to deliver an improved Australasian road transport network. To succeed in this task, we undertake leading-edge road and transport research which underpins our input to policy development and published guidance on the design, construction and management of the road network and its associated infrastructure.

Austroads provides a collective approach that delivers value for money, encourages shared knowledge and drives consistency for road users.

Austroads is governed by a Board consisting of senior executive representatives from each of its eleven member organisations:

- Roads and Maritime Services New South Wales
- Roads Corporation Victoria
- Queensland Department of Transport and Main Roads
- Main Roads Western Australia
- Department of Planning, Transport and Infrastructure South Australia
- Department of State Growth Tasmania
- Department of Infrastructure, Planning and Logistics Northern Territory
- Transport Canberra and City Services Directorate, Australian Capital Territory
- Australian Government Department of Infrastructure and Regional Development
- Australian Local Government Association
- New Zealand Transport Agency.

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Mr Rob Grove	Main Roads Western Australia
Mr Noel O’Callaghan	Department for Transport, Energy and Infrastructure, South Australia
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Mr Peter Toll	Department of Planning and Infrastructure, Northern Territory
Mr Ken Marshall	ACT Department of Territory and Municipal Services
Mr Peter Aumann	Australian Local Government Association
Mr James Hughes	NZ Transport Agency
Mr Tom Brock	The Association of Consulting Engineers
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It is also acknowledged that much of the information in this guide is based on an internal Roads and Traffic Authority of New South Wales document (RTA 2008).

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1. Introduction

1.1 Purpose

Austroads *Guide to Road Design* seeks to capture the contemporary road design practice of member organisations (refer to the *Guide to Road Design – Part 1: Introduction to Road Design,* Austroads 2006a). In doing so, it provides valuable guidance to designers in the production of safe, economical and efficient road designs.

There are three parts of the *Guide to Road Design* that collectively deal with the design of roadsides:

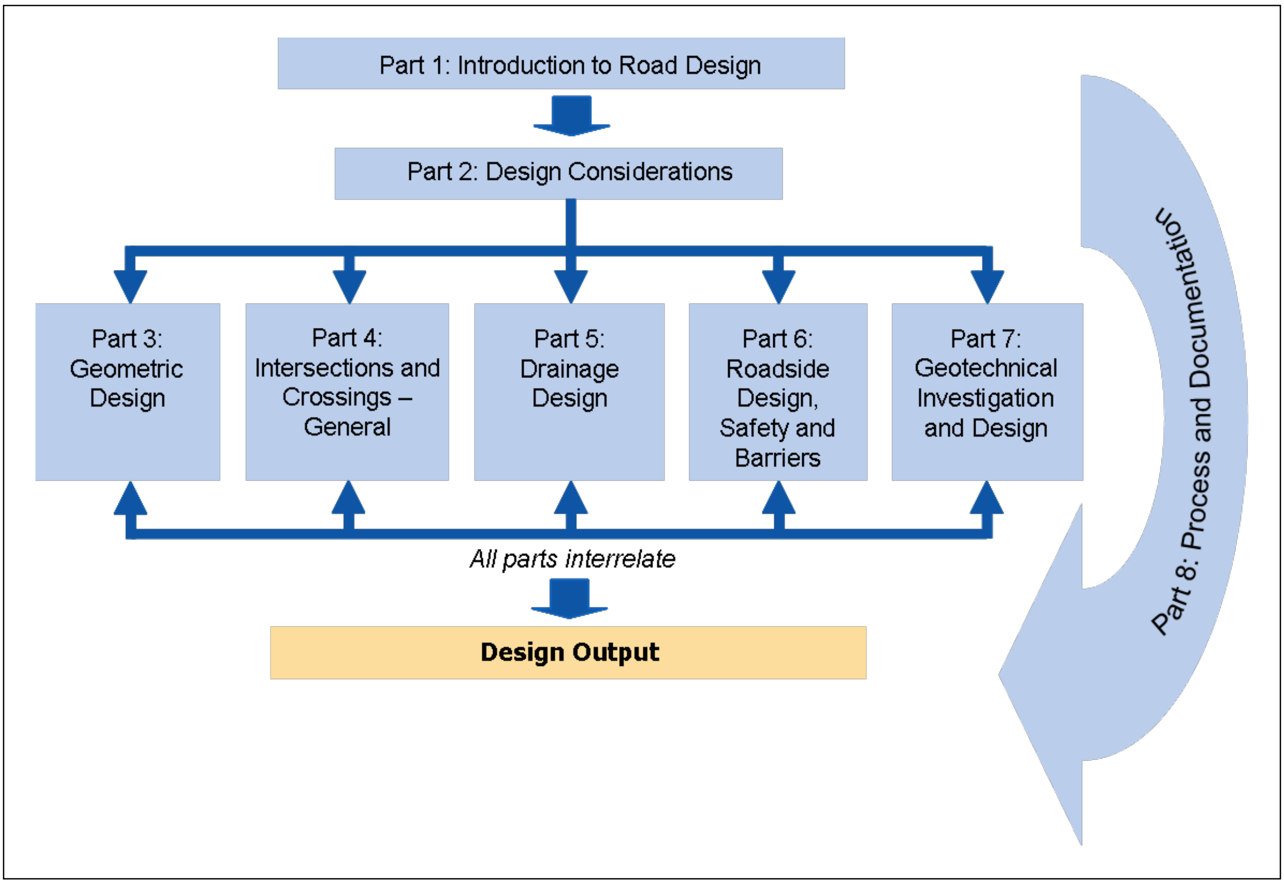
- Part 6: Roadside Design, Safety and Barriers.
- Part 6A: Pedestrian and Cyclist Paths (Austroads 2009g).
- Part 6B: Roadside Environment (Austroads 2009h).

The collective purpose of these documents is to:

- promote a uniform approach to roadside design and safety by road authorities throughout Australia and New Zealand
- provide road design and road safety practitioners with:
  - an understanding of roadside safety issues including the assessment of risk
  - guidance on the design of the roadside and infrastructure that must be accommodated within the road reservation.

Figure 1.1 shows the broad context in which Part 6 (including Parts 6A and 6B) is applied. It can be seen that Part 6 is one of eight guides that comprise the Austroads *Guide to Road Design* and provide information on a range of disciplines including geometric design, intersections and crossings, drainage and geotechnical design, all of which may influence the space available within a roadside and the design of features and infrastructure within it.

Figure 1.1: Flow chart of the Guide to Road Design



In relation to Figure 1.1 it should be noted that the Part 4 of the *Guide to Road Design* comprises four parts, namely:

- Part 4: Intersections and Crossings – General (Austroads 2009c)
- Part 4A: Unsignalised and Signalised Intersections (Austroads 2009d)
- Part 4B: Roundabouts (Austroads 2009e)
- Part 4C: Interchanges (Austroads 2009f).

Whilst Figure 1.1 outlines the structure of the *Guide to Road Design*, designers should be aware that there are nine other subject areas spanning the range of Austroads publications that may also be relevant to roadside design and safety and can be accessed via www.austroads.com.au.

1.2 Scope of this Part

The *Guide to Road Design – Part 6: Roadside Design, Safety and Barriers* provides an introduction to the design of the roadside and the many features and objects that may have to be accommodated and coordinated in the space between the edge of the carriageway and the reservation boundary, and within medians. However, the major focus of Part 6 is that it provides guidelines for the hazard identification and mitigation process and gives a clearly defined process for designing roads for safety.

Specifically, Part 6 provides:

- guidelines on the rationale of errant vehicle management
- guidelines for assessment and treatment of hazards on the roadside

- guidance on the selection and location of road safety barriers
- a road design process that implements errant vehicle management principles and risk management.

Whilst some consideration is given in this guide to motorcyclists and cyclists with respect to safety barriers, it should be understood that the hazard mitigation process and severity indices presented and discussed in this guide relate to the occupants of cars.

Part 6 deals with the design for errant vehicles and the roadside hazards with which an errant vehicle may collide. A vehicle becomes errant when it leaves the travelled path onto the verge, or onto (or across) the median. Apart from cross-median head-on crashes Part 6 does not deal with the management of crashes on the carriageway or at intersections. However, Part 6 also describes design considerations, treatment options and countermeasures that are available for keeping vehicles on the road and for minimising the possibility of collision with roadside hazards.

1.3 Road Safety

Part 6 should be considered in the broad context of road safety and the contribution that the guide can make to the design of safer roads.

1.3.1 Providing for a Safe System

Adopting a safe system approach to road safety recognises that humans as road users are fallible and will continue to make mistakes, and that the community should not penalise people with death or serious injury when they do make mistakes. In a safe system, therefore, roads (and vehicles) should be designed to reduce the incidence and severity of crashes when they inevitably occur.

The safe system approach requires, in part (Australian Transport Council 2006):

- Designing, constructing and maintaining a road system (roads, vehicles and operating requirements) so that forces on the human body generated in crashes are generally less than those resulting in fatal or debilitating injury.
- Improving roads and roadsides to reduce the risk of crashes and minimise harm: measures for higher speed roads including dividing traffic, designing ‘forgiving’ roadsides, and providing clear driver guidance. In areas with large numbers of vulnerable road users or substantial collision risk, speed management supplemented by road and roadside treatments is a key strategy for limiting crashes.
- Managing speeds, taking into account the risks on different parts of the road system.

Safer road user behaviour, safer speeds, safer roads and safer vehicles are the four key elements that make a safe system. In relation to speed the Australian Transport Council (2006) reported that the chances of surviving a crash decrease markedly above certain speeds, depending on the type of crash, as follows:

- pedestrian struck by vehicle → 20 to 30 km/h
- motorcyclist struck by vehicle (or falling off) → 20 to 30 km/h
- side impact vehicle striking a pole or tree → 30 to 40 km/h
- side impact vehicle to vehicle crash → 50 km/h
- head-on vehicle to vehicle (equal mass) crash → 70 km/h

In New Zealand, practical steps have been taken to give effect to similar guiding principles through a Safety Management Systems (SMS) approach.

Road designers should be aware of, and through the design process actively support, the philosophy and road safety objectives covered in the Austroads *Guide to Road Safety*.

1.3.2 Contribution of Roadside Design to Road Safety

A key component of the safe system approach is safer roads. As a large percentage of crashes on road networks, particularly in rural areas, involve run-off-road crashes, it follows that the design of the roadside and features within it can either adversely affect road safety or, alternatively, contribute to a safer environment for all road users. The prime road environment safety objective is to reduce crashes and casualties by improving the road environment and the management of traffic.

The sides of rural roads have to accommodate various features and infrastructure such as open drains, traffic signs and their supports and road safety barriers, while urban roads usually have to accommodate paths, public utilities, landscaping and other facilities. At greenfield sites, all roadside features and infrastructure should be designed to support the safe systems approach by minimising the roadside risk for errant drivers. Road designers and practitioners therefore have the potential to make a major contribution to crash reduction by applying best practice in the design of roadsides. In addition, the process and information in Part 6 can be applied in the assessment and treatment of brownfield sites.

1.4 Terminology

The *Glossary of Austroads Terms* (Austroads 2008a) provides a comprehensive account of terms that relate to its guides. However, it is important for practitioners to be familiar with specific terms associated with roadside safety and road safety barriers and for convenience these terms are defined in Appendix A.

2. Roadside Design

2.1 General

Roadside design includes the design of all features and infrastructure that need to be accommodated in the area between the reserve boundary and the nearest road shoulder (or kerb) and within medians.

Features associated with the design of the road itself and which exist within the roadside are concerned with cross-section (e.g. verges; embankments) or drainage (e.g. open drains; inlets and outlets to transverse culverts) and are covered in the *Guide to Road Design – Part 3: Geometric Design* (Austroads 2009b) and the *Guide to Road Design – Part 5: Drainage Design* (Austroads 2008b). However, the design of elements associated with cross-section and drainage may also have to consider an extensive range of other requirements within the road reservation.

It is important that the design brief for a road design sets out not only the design standards for alignment and cross-section, and other engineering requirements, but also the location and extent of the other facilities or infrastructure that needs to be accommodated. This information should result from a planning study or liaison with other authorities and in some instances may take the form of a conceptual layout. With a clear brief the road designer should be able to develop a roadside design that accommodates and coordinates all the requirements of road users and other stakeholders or alternatively, identifies areas of conflict that require further investigation and/or negotiation.

2.2 Roadside Facilities and Infrastructure

Parts 6, 6A and 6B of the *Guide to Road Design* cover an extensive range of facilities and infrastructure that may need to be considered and are listed below.

2.2.1 Part 6: Roadside Design, Safety and Barriers

This part covers the:

- clear zone requirements for various traffic conditions and batter slopes
- treatment and design of features and objects in the roadside to remove or mitigate a hazard
- the provision of road safety barriers to shield roadside hazards including the types, length and clearances required
- design of other road safety related devices such as runaway vehicle ramps and heavy vehicle arrester beds.

2.2.2 Part 6A: Pedestrian and Cyclist Paths

The *Guide to Road Design – Part 6A: Pedestrian and Cyclist Paths* (Austroads 2009g) covers the need for paths and the geometric design of footpaths, shared paths and bicycle paths both within roadsides and in reservations that are remote from roads but may intersect with them.

2.2.3 Part 6B: Roadside Environment

The *Guide to Road Design – Part 6B: Roadside Environment* (Austroads 2009h) covers the roadside facilities and infrastructure that are not directly associated with roadside safety, safety barriers, or pedestrian and cyclist paths. It should be noted that the purpose of this guide is to provide the guidance necessary for a road designer to have sufficient knowledge of the subject areas to ensure that they are considered and integrated into a road design. It is expected that the designer will have to involve experts in various fields to resolve requirements for:

- environmental aspects such as stormwater run-off, fauna management and noise control
- landscaping
- roadside amenity including visual amenity and rest facilities
- roadside infrastructure such as road furniture, lighting, emergency/help telephones, off-street parking and utilities.

3. Designing for Safety

3.1 General

The broad safety context in which roadside safety must be considered is described in Section 1.3. The provision of a safe road environment involves the application of appropriate standards for road design, construction and maintenance. The standard adopted in a particular situation will be influenced by a range of factors and considerations that are discussed in other parts of the *Guide to Road Design*.

In any situation the road itself should be designed to minimise the likelihood that any aspect of the design will contribute to errant vehicles leaving the road. However, in the event that a vehicle does leave the road it is most desirable that the roadside is designed to minimise the likelihood of a crash occurring and to minimise the severity of any crash that does occur.

Road designers are required to develop designs for greenfield and brownfield sites and this guide is intended to apply to both situations. While greenfield sites may offer designers greater flexibility it is unlikely that it will be possible for designers to avoid, remove, or relocate all potential roadside hazards. The design may therefore require assessment, treatment and shielding of roadside hazards.

3.2 A Safe Road Environment

The initial approach to hazard management is to design roads to keep vehicles on the road and prevent vehicles from becoming errant. This need for this approach was adequately expressed in a safety review of a highway in Canada (Professional Engineers of Ontario 1997):

> *The fact that almost all crashes could have been prevented had the involved persons acted differently does not mean that the most effective way to reduce crashes is to alter people's behaviour or tendency to make errors. Effective action must aim jointly at the human element, the vehicle and the road. Road design can reduce the incidence of human error, road design can reduce the chance of a human error to end up as a crash, and road design can ameliorate the severity of crashes that are initiated by human error.*

A safer road environment can be achieved by ensuring that the road design is as safe as possible and that the safety is verified before the road is built from the design drawings. This is achieved through design processes that include audits at various stages in the development of a road design (refer to the *Guide to Road Design – Part 8: Process and Documentation,* Austroads 2009i).

It is not only the safety of the car driver that should be considered, but that of other road users such as pedestrians, cyclists and motorcyclists, as well as persons occupying properties which might be impacted by traffic crashes.

Road and roadside design for errant vehicles should involve:

- a design process that gives consideration to the safety of all road users and produces a forgiving road environment
- design to keep vehicles on the road
- an assessment of the roadside and appropriate action to reduce the risks of roadside hazards through their removal or mitigation
- provision of road safety barriers through a risk assessment process
- choice of road safety barriers through a rigorous acceptance process.

These requirements are essential to providing the safest possible environment for all road users.

3.3 Design for Risk Reduction

Road design aims to achieve a practical and economic balance between the assessed risks of hazardous consequences and the measures needed to mitigate those risks.

Most risks, or combination of risks, can be treated in a number of ways. The choice of treatment methods should aim to provide a cost-effective solution consistent with a reduction in the risk of impact with a particular hazard or hazards. Sometimes a number of smaller and cheaper treatments may be just as effective as a single larger treatment which is more expensive.

The systematic approach to risk reduction in design involves:

- reduction of the inherent hazard
- prevention of an incident
- limiting damage.

3.3.1 Reduce Inherent Hazard

The objective of an inherently safe design is to either eliminate hazards or to ensure that the level of roadside risk to road users is very low. Whilst the risk associated with hazards can be reduced through engineering treatments, it should be understood that these treatments may also be hazardous to the occupants of errant vehicles.

For the following reasons the elimination of hazards should always be preferred to adding safety devices and other layers of protection to make the hazards safer:

- A hazard is still present although the severity of an impact with the device or treatment may be less than an impact with the hazard that is being shielded.
- There is always the potential for a crash due to simultaneous failure of several layers of protection, or degradation of the layers of protection in the future.

A design which is inherently safe is better than the use of safety devices (e.g. adding road safety barriers) that can be hazardous to road users and can also add significant maintenance costs over the operational life of the road. It should be understood that safety barriers and other safety devices are also a form of roadside hazard as they can result in significant damage to errant vehicles and injury to the occupants, and can be particularly severe with respect to errant motorcyclists. Therefore, they are used to reduce the inherent hazard and should only be used where less severe treatments are impracticable.

While inherent safety represents the first and most desirable way to manage risk, the prevention of incidents and minimisation of damage in a crash can also be used effectively to reduce risk.

3.3.2 Prevent an Incident

Prevention of an incident is the second step in balanced risk reduction. In transport operation, accidents usually arise because of loss of control and/or loss of containment (of a hazardous material or vehicle). Preventing the loss of control or the loss of containment is an effective risk control. Matching horizontal curve radii to the operating speed is an example of incident prevention.

3.3.3 Limit Damage

If a vehicle leaves the road and there is a hazard present that cannot be removed the hazardous consequences of an incident can be limited, often through the provision of protection systems. The use of a road safety barrier to reduce impact severity is an example of limiting damage, as is the choice of a barrier that results in less severe impact for vehicle occupants during a crash.

Protection systems can be put in place to protect against hazardous consequences if an incident occurs. Protection systems provide a backup when normal facilities for control or containment fail (i.e. when prevention of the incident fails). Road safety barriers are an example of a protection system.

3.4 Design to Keep Vehicles on the Road

3.4.1 General

Whether a road design involves a new road in a greenfield site, upgrading the geometry of an existing road, or an investigation of roadside hazards on an existing road, a key objective is to ensure that no element of the road design is a contributing factor to run-off-road incidents. This is a prerequisite to the hazard mitigation process.

When designing a new road or considering the adequacy of an existing road, practitioners should refer to the *Guide to Road Design – Part 3: Geometric Design* (Austroads 2009b). All practical and economically feasible measures should be taken to prevent vehicles from leaving the road in addition to providing a safe roadside which may involve shielding hazards to prevent drivers who leave the road from crashing into them. The likelihood that a vehicle will leave either side of the road may depend on many factors relating to the driver, the road and the environment as described in Commentary 1.

Whilst drivers on two-way roads often leave the road on the left side, significant numbers of drivers also leave the road on the right side of roads or are involved in head-on crashes. Designers should therefore ensure that hazards on two-way roads are shielded from impact by errant vehicles originating from both directions of travel. Where a significant head-on crash problem exists as a result of fatigue or overtaking, a road authority may consider the use of a central barrier on a two-lane two-way road (Figure 3.1) as some research and experience has been gained in the use of this treatment option. However, this treatment is a special case that should only be used in critical locations.

Figure 3.1: Wire rope safety barrier centrally located on a two-lane two-way road

3.4.2 Combining Design Parameters and Consistent Design

In order to give drivers the best chance of keeping their vehicles on the road it is necessary to provide a geometric design conducive to safe travel. Safety on roads is closely related to the driver's ability to anticipate events and react to them.

A safe road design does not necessarily require a wide pavement and alignment designed to accommodate a high speed but is one in which on-road and roadside features clearly show drivers the path that a road takes and helps them keep their vehicles in the running lane.

Roads must be contained within the topography in a cost-effective way and this may require that a particular design speed and cross-section is adopted to suit the function of the road, traffic characteristics and topography. The road design in these circumstances should enable the driver to travel safely at the intended design speed on a consistent alignment. In summary the following considerations are important:

- Combinations of design parameters – the adoption of lower order values for a number of design parameters in combination may create an unsafe design even though the individual design parameters are in compliance with guidelines.
- Consistent design environment – a safe road design is one that has on-road and roadside features that clearly show drivers the path that a road takes and helps them keep their vehicles in the running lane.
- Vehicle mix considerations – it is important to consider the impact and additional risk of a higher than normal percentage of heavy vehicles, particularly where steep grades are involved.
- Other specific design elements and features – (e.g. horizontal and vertical alignment, lane widths, drainage etc.).

Further information is provided in Commentary 2.

4. Design to Mitigate Hazards

4.1 Hazard Mitigation Process

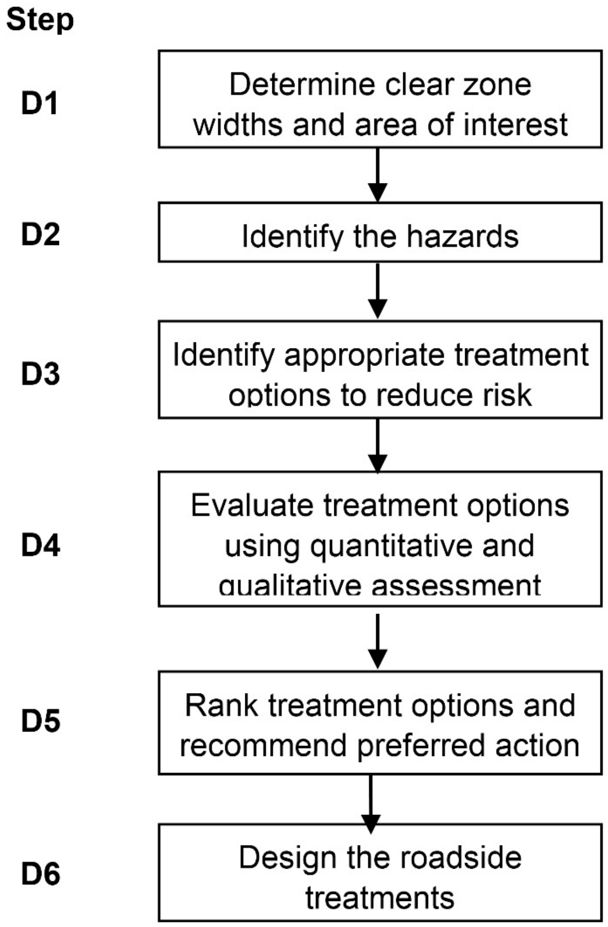
For existing roads the provision of a safe roadside involves removing or treating hazards that may result in a crash or contribute to the severity of a crash. In the case of new roads a safe roadside is achieved by ensuring that an adequate area is provided immediately adjacent to the road that is both free of obstacles and designed so that drivers are able to regain control of their vehicles. With respect to roadside safety it would be desirable to provide a clear width adjacent to the carriageway that would allow all errant vehicles to recover. However, this is often not feasible and it is therefore necessary to design a roadside that has an acceptable level of risk.

The design process to mitigate hazards involves the identification and assessment of features and objects that may be hazardous to errant vehicles. Figure 4.1 illustrates a generic process that involves the following steps:

- Step 1: Determination of clear zone widths and an area of interest
- Step 2: Identification of hazards
- Step 3: Identification of appropriate treatment options
- Step 4: Evaluation of practicable treatment options including a risk assessment
- Step 5: Ranking of treatment options and a recommended a course of action (e.g. remove hazard, install road safety barrier)
- Step 6: Design the recommended roadside treatments.

Steps D1 to D4 in Figure 4.1 are discussed in Sections 4.2 to 4.5 and Steps D5 and D6 are discussed in Sections 4.7 and 4.8 respectively. An example of a hazard mitigation worksheet that may be used to facilitate the design process is contained in Appendix B.

Figure 4.1: Hazard mitigation process



4.2 Design Step D1: Determine Area of Interest

4.2.1 General

A prerequisite to the identification and assessment of hazards for both new roads and existing roads is to ensure that the road itself is designed and maintained in a way that should enable drivers to keep their vehicles on the road when travelling at an appropriate speed (refer to Section 3.4).

This section describes the principles applied in identifying hazards for assessment and possible treatment.

4.2.2 Determine the Clear Zone

The identification of hazards in Australia and New Zealand is generally based on the use of the clear zone concept to define the area beside the road that is of most interest in terms of roadside safety. However, designers should note that the Roads and Traffic Authority of New South Wales (RTA) defines a hazard corridor based on similar principles.

What is a clear zone?

In order to have a manageable risk assessment process it is necessary to define an area beside the road that will envelop the majority of hazards that are of interest. This entails defining a width from the nearest through travel lane within which the risk of all hazards should be assessed. Ideally from a roadside safety perspective this area would be clear of all hazards; hence the term clear zone.

> *A clear zone is the area adjacent to the traffic lane that should be kept free from features that would be potentially hazardous to errant vehicles. The clear zone is a compromise between the recovery area for every errant vehicle, the cost of providing that area and the probability of an errant vehicle encountering a hazard. The clear zone should be kept free of non-frangible hazards where economically and environmentally possible. Alternatively, hazards within the clear zone should be treated to make them safe or be shielded by a safety barrier (Austroads 2008a).*

Considerations in applying clear zones to designs

Clear zones should be applied to both rural and urban road designs in greenfield sites. However, the application of the concept to well established urban environments (i.e. brownfield sites) is usually problematic because of the lack of space, and objects (e.g. utilities and road furniture) that have been accommodated at the side of the road.

In both the clear zone and hazard corridor processes, hazards are assessed one at a time and may be disregarded for treatment if the risk is low. However, in practice a combination of hazards often occurs in close proximity to each other and the designer should assess whether they can be mitigated by the one treatment. Therefore, when assessing a location that has a combination of hazards, designers should consider whether they collectively have a severity greater than the sum of the severities of the individual hazards. For example, the severity of an impact with a rigid object at the base of a steep rock pitched batter may be considerably higher than impact with the same rigid object on flat ground.

It should be noted that the clear zone (refer to Table 4.1) or hazard corridor (refer to Appendix C) distances provided in this guide may not cater for all vehicle types (e.g. trucks and motorcycles) as the distances have been developed primarily in relation to light vehicles (refer to Section 6.3.13 regarding design for heavy vehicles).

The clear zone on a particular road will not necessarily be constant as the distance may vary depending on road geometry such as the presence of embankments or curves, vehicle operating speeds and traffic volume.

Designers should be aware that the clear zone width is only applicable to low angle departures. As the angle of departure increases, the likelihood of vehicle recovery within the clear zone reduces because a recovery manoeuvre becomes less likely and the only option for the driver is to attempt to stop the vehicle and avoid hazards.

The ground surface within a clear zone should be traversable by vehicles as any holes, obstacles or steep slopes may cause a vehicle undercarriage to become snagged with the result that the driver loses control or the vehicle rolls. For example, the use of rock spalls (i.e. large rocks that are not mortared) within the clear zone is not preferred as it can affect the stability of an errant vehicle whereas rock pitching (i.e. small rocks mortared) may be acceptable provided that the rocks do not protrude excessively above the mortared joints.

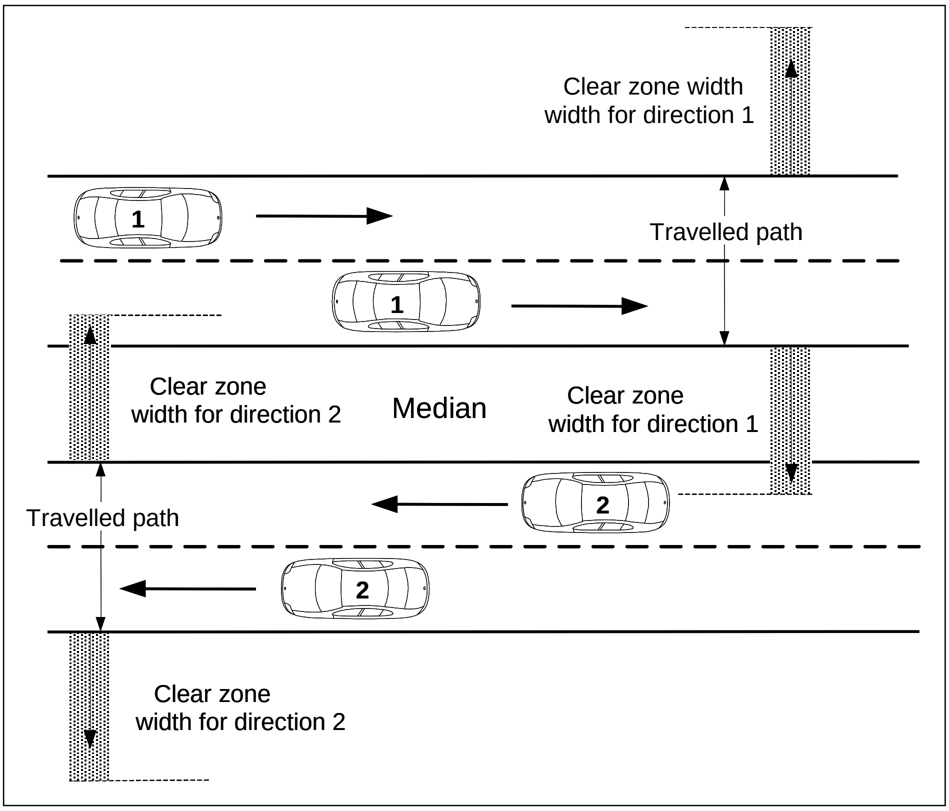
Hazards that lie outside the clear zone will generally not require assessment because the locations are a sufficient distance from the edge of the road that the probability of a collision is relatively small. However, whilst the clear zone should provide an adequate level of safety in most situations it is known that a significant proportion of errant vehicles (up to 20%) may come to rest beyond the clear zone. This aspect is discussed further in Commentary 3. It is therefore essential that designers are also aware of potential hazards that exist beyond the clear zone, as in special circumstances significant hazards outside the area may require assessment and treatment.

Where there is an auxiliary lane adjacent to the through lane it is appropriate to consider the auxiliary lane width as part of the clear zone required for the through lane. However, the clear zone required for drivers using the auxiliary lane should also be considered. The clear zone for turning lanes should be determined by allowing for appropriate deceleration and a reduced speed, or in the case of an acceleration lane by determining the likely speed adjacent to the hazard being considered. A separate analysis should be done for the through lane and the auxiliary lane.

Vehicles are considered errant when they leave the travelled path onto either the median or the verge. For this reason, the area of interest for hazards applies on both sides of the travelled path and each side must be independently derived according to the road conditions. The implications of this for multi-lane divided roads and for two-lane, two-way roads is illustrated in Figure 4.2 and Figure 4.3 respectively.

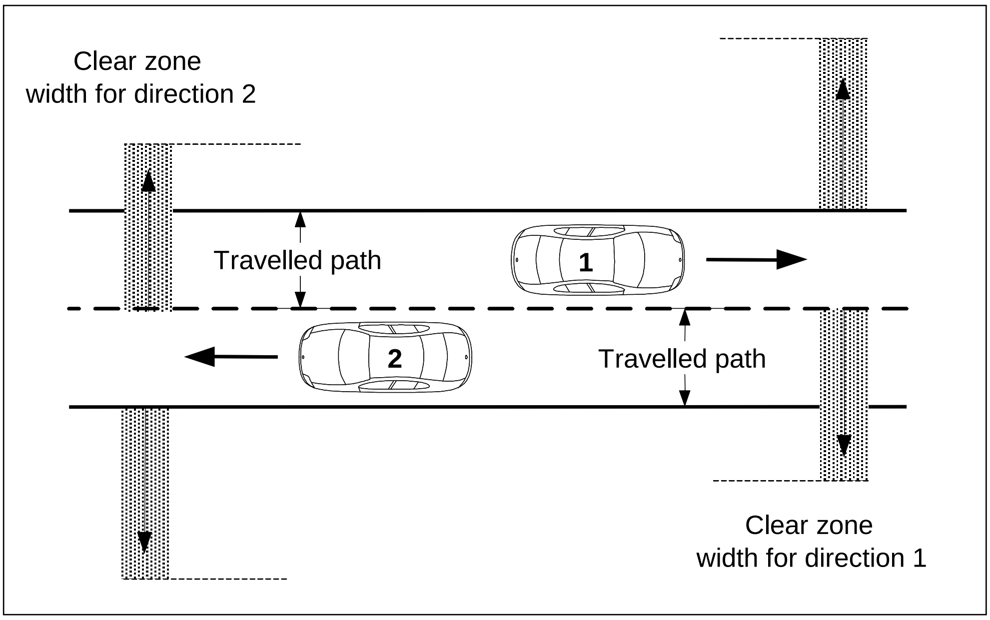
It should be noted that a vehicle that crosses the centre line or median into the opposite carriageway is an errant vehicle. If the clear zone includes at least part of an opposing traffic lane, approaching vehicles must be considered as hazards for the purposes of road design. This is always the case for two-lane, two-way roads, and may be the case for multi-lane divided roads.

Figure 4.2: Clear zone on multi-lane divided roads



Source: Adapted from RTA (2008).

Figure 4.3: Clear zone on two-lane, two-way roads



Source: Adapted from RTA (2008).

Clear zone width

Australian and New Zealand jurisdictions generally prefer to determine the clear zone width from Table 4.1 that is used by the American Association of State Highway and Transportation Officials (AASHTO 2006). According to AASHTO (2006) the table can be used to determine a suggested clear zone width that is considered to provide only a general approximation of the needed clear zone distance. The values are based on limited empirical data that was extrapolated to provide information for a wide range of conditions. The values provided are not regarded as absolute but as a guide which designers may increase (and occasionally decrease) depending on site-specific conditions and practicality.

Table 4.1: Clear zone distances from edge of through travelled way

Design speed (km/h)	Design ADT	Clear zone width (m)					
		Fill batter			Cut batter		
		6:1 to flat	4:1 to 5:1	3:1 and steeper(2)	6:1 to flat	4:1 to 5:1	3:1 and steeper(2)
≤ 60	< 750	3.0	3.0	(2)	3.0	3.0	3.0
	750 – 1500	3.5	4.5	(2)	3.5	3.5	3.5
	1501 – 6000	4.5	5.0	(2)	4.5	4.5	4.5
	> 6000	5.0	5.5	(2)	5.0	5.0	5.0
70 – 80	< 750	3.5	4.5	(2)	3.5	3.0	3.0
	750 – 1500	5.0	6.0	(2)	5.0	4.5	3.5
	1501 – 6000	5.5	8.0	(2)	5.5	5.0	4.5
	> 6000	6.5	8.5	(2)	6.5	6.0	5.0
90	< 750	4.5	5.5	(2)	3.5	3.5	3.0
	750 – 1500	5.5	7.5	(2)	5.5	5.0	3.5
	1501 – 6000	6.5	9.0	(2)	6.5	5.5	5.0
	> 6000	7.5	10.0(1)	(2)	7.5	6.5	5.5

Design speed (km/h)	Design ADT	Clear zone width (m)					
		Fill batter			Cut batter		
		6:1 to flat	4:1 to 5:1	3:1 and steeper(2)	6:1 to flat	4:1 to 5:1	3:1 and steeper(2)
100	< 750	5.5	7.5	(2)	5.0	4.5	3.5
	750 – 1500	7.5	10.0(1)	(2)	6.5	5.5	4.5
	1501 – 6000	9.0	12.0(1)	(2)	8.0	6.5	5.5
	> 6000	10.0(1)	13.5(1)	(2)	8.5	8.0	6.5
110	< 750	6.0	8.0	(2)	5.0	5.0	3.5
	750 – 1500	8.0	11.0(1)	(2)	6.5	6.0	5.0
	1501 – 6000	10.0(1)	13.0(1)	(2)	8.5	7.5	6.0
	> 6000	10.5(1)	14.0(1)	(2)	9.0	9.0	7.5

1 *Where a site specific investigation indicates a high probability of continuing crashes, or such occurrences are indicated by crash history, the designer may provide clear zone distances greater than the clear zone shown in Table 4.1. A jurisdiction may limit clear zones to 9 m for practicality and to provide a consistent roadway template if previous experience with similar projects or designs indicates satisfactory performance.*

2 *Since recovery is less likely on the unshielded, traversable 3:1 slopes, fixed objects should not be present in the vicinity of the toe of these slopes. Recovery of high-speed vehicles that encroach beyond the edge of the shoulder may be expected to occur beyond the toe of the slope. Determination of the recovery area at the toe of the slope should take into consideration available road reservation, environmental concerns, economic factors, safety needs, and crash histories. Also, the distance between the edge of the travelled lane and the beginning of the 3:1 slope should influence the recovery area provided at the toe of the slope. While the application may be limited by several factors, the fill slope parameters which may enter into determining a maximum desirable recovery area are illustrated in Figure 4.4.*

Notes:

The design ADT in the table is the average daily traffic volume in both directions and in all lanes, other than for divided roads where it is the total traffic in all lanes in one direction.

Where the road is curved the values in Table 4.1 should be adjusted by the curve correction factors in Table 4.2.

The RTA New South Wales uses a similar approach based on a hazard corridor and with curve adjustments included rather than ADT (Appendix C). For the same situation the RTA method results in greater clear zones than those shown in Table 4.1.

Source: Adapted from AASHTO (2006).

It can be seen from Table 4.1 that the factors affecting the clear zone width are the:

- design speed because errant vehicles travel further with increasing speed
- traffic volume because increased exposure of road users to a hazard means that more vehicles are likely to leave the road
- roadside slope because of the effect of slope on a driver’s ability to recover from an incident
- road curvature because it can affect the lateral distance travelled by an errant vehicle (Table 4.2).

Worked examples of clear zone calculations are provided in Appendix D.

It should be noted that under the RTA NSW method traffic volume does not influence the width of the hazard corridor (which is an ‘area of interest’ in which hazards will be assessed), which differentiates it from the AASHTO clear zone method (which is a space that will desirably be cleared of all objects). In the RTA NSW method the effect of traffic volume is considered when calculating the risk of hazards within the corridor.

Effect of embankment slope

Steep embankment slopes may not constitute a direct hazard but prevent errant vehicles from recovering when they leave the road and run onto the embankment. It should be noted that the condition of the surface is a factor on whether a steep embankment is a hazard to errant drivers (i.e. the undercarriage of some vehicles may snag on low obstacles and roll over).

Embankment slopes can be classified as recoverable or non-recoverable.

Recoverable embankment slopes have a slope of 4:1 or flatter. If these slopes are traversable, no adjustment is required to the clear zone width. To make the slopes traversable, the top of the slope should be rounded to help an encroaching vehicle remain in contact with the ground. It is also desirable for the toe of the slope to be rounded where the toe occurs within the clear zone.

Non-recoverable embankment slopes are slopes steeper than 4:1. Most vehicles on slopes this steep will continue to the bottom of the slope. Therefore, an errant vehicle recovery area beyond the toe of the non-recoverable embankment slope is required (i.e. a non-recoverable embankment slope should not be included as part of the clear zone width). It is recommended that the top of the slope be rounded so that an encroaching vehicle does not become airborne.

Critical slope is a sub-set of non-recoverable slopes. Embankment slopes (i.e. foreslopes) are regarded as critical if the slope exceeds 3:1 as at this slope vehicles are likely to overturn. A barrier might be warranted if a foreslope steeper than 3: 1 is situated closer to the through travelled way than the suggested clear zone distance for that specific roadway, and if the slope cannot be readily flattened (AASHTO 2006).

It is most important that road designers and road managers understand that the satisfactory performance of a clear zone within an embankment requires the batter to be smooth and free of any objects that could snag the undercarriage of errant cars and of any holes that could prevent a driver from controlling a vehicle on the slope.

In addition, a clear run-out area may be required at the bottom of the embankment. The determination of the clear run-out width is described in Note 2 under Table 4.1 and in the note within Figure 4.4. However, the minimum width of the clear run-out area should be 3.0 m (Austroads 2003) to provide for an errant car to satisfactorily come to rest. It is important that the run-out area also has a smooth surface and contains no hazardous objects or features.

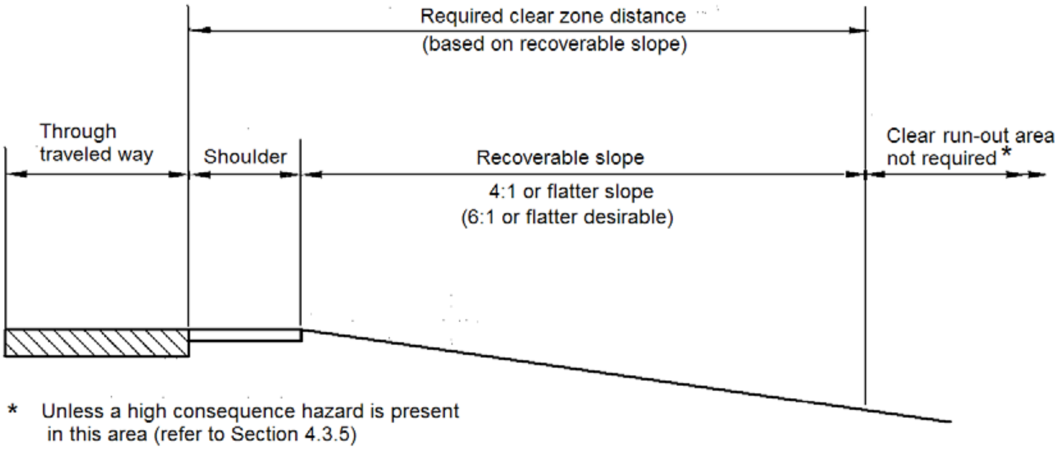
Figure 4.4 illustrates parallel fill slope designs on both recoverable and non-recoverable slopes, the latter requiring a run-out area at the bottom of the slope. However, it is noted that the values of foreslopes described previously and shown in the figure apply to cars and that a safe roadside design for trucks would require much flatter slopes as follows:

- 10:1 is recoverable for trucks
- 6:1 is traversable for trucks
- 4:1 cannot be safely traversed by trucks
- 6:1 is recoverable for cars
- 4:1 is traversable for cars
- ≥ 3:1 cannot be safely traversed by cars.

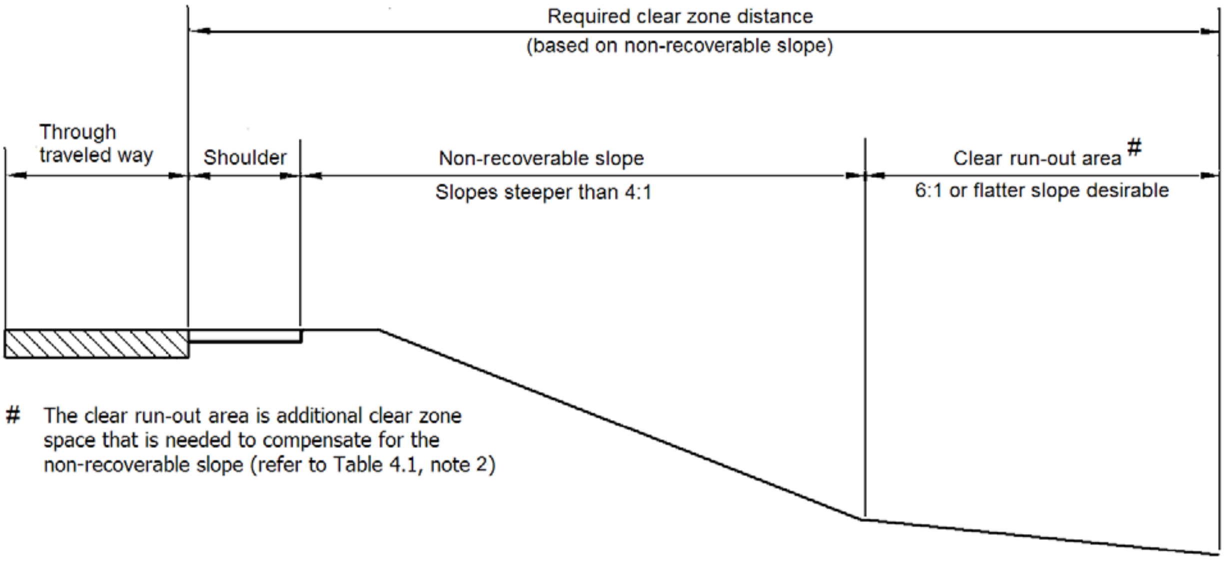
It follows that a safe roadside should ideally have flat foreslopes, particularly if they are to be safe for errant trucks.

A more detailed process for assessing the treatment of embankments is discussed in Section 4.3.4.

Figure 4.4: Example of a parallel fill slope design illustrating clear zone and slopes



(a) Clear zone on recoverable slope



(b) Clear zone on a non-recoverable slope

The clear zone distance from Table 4.1 should also be adjusted where the road is on a horizontal curve by multiplying it by the appropriate curve correction factor from Table 4.2. However, the correction only applies to clear zones on the outside of curves and these modifications are considered only when:

- crash histories indicate a need
- a specific site investigation shows a definitive crash potential that could be significantly reduced by increasing the clear zone width, and
- such increases are cost-effective.

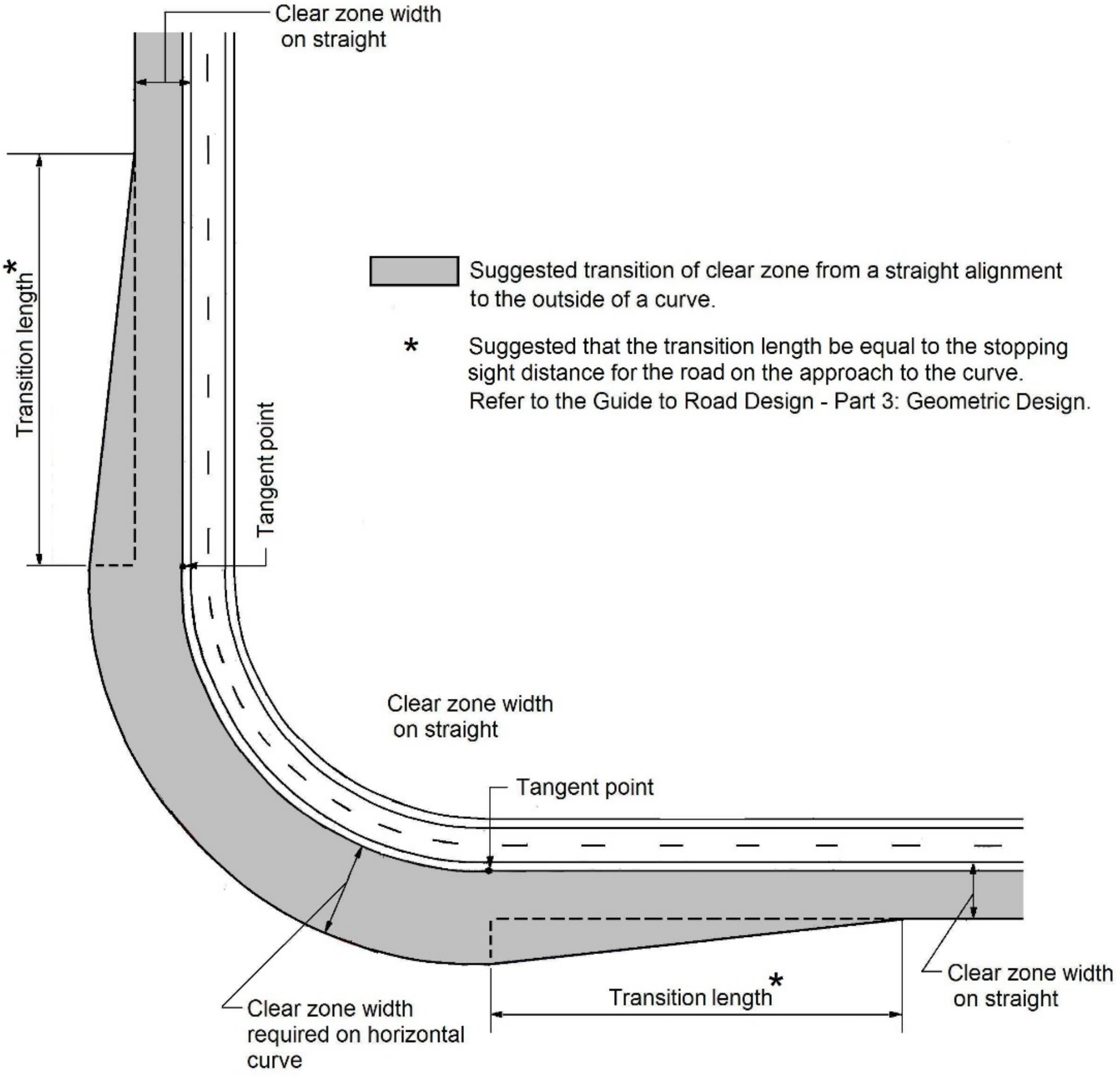
Table 4.2: Curve correction factors

Radius (m)	Design speed (km/h)					
	60	70	80	90	100	110
900	1.1	1.1	1.1	1.2	1.2	1.2
700	1.1	1.1	1.2	1.2	1.2	1.3
600	1.1	1.2	1.2	1.2	1.3	1.4
500	1.1	1.2	1.2	1.3	1.3	1.4
450	1.2	1.2	1.3	1.3	1.4	1.5
400	1.2	1.2	1.3	1.3	1.4	–
350	1.2	1.2	1.3	1.4	1.5	–
300	1.2	1.3	1.4	1.5	1.5	–
250	1.3	1.3	1.4	1.5	–	–
200	1.3	1.4	1.5	–	–	–
150	1.4	1.5	–	–	–	–
100	1.5	–	–	–	–	–

Source: AASHTO (2006).

It can be seen from Table 4.2 that where a straight section of road joins a curve the clear zone may increase in width by up to 50%. In such cases it is desirable to provide a transition from the lesser width on the straight to the greater width required through the curve. The transition should occur prior to the tangent point so that the extra width is provided where it is likely to be needed. It is suggested that the transition occur over a nominal length equivalent to the stopping sight distance for the section of road as illustrated in Figure 4.5.

Figure 4.5: Clear zone transition on approach to horizontal curves



4.2.3 Application of Clear Zones to Design

The process of applying the clear zone concept to design involves determining the width of the required clear zone to establish an area (or corridor) of interest in which hazards will be identified, noting that the width at any particular point will depend on several factors. The widths and area of interest may be marked up on plans.

For each road section, the base clear zone width (i.e. prior to allowance for non-recoverable slope and provision of a run-out area at the toe) is obtained from Table 4.1. Each direction of travel is considered separately as illustrated in Figure 4.2 and Figure 4.3.

Plotting the area of interest on plans will ensure that wherever practicable roadside furniture and features (e.g. landscaping, sign supports, culvert end treatments, etc.) are designed to be outside the clear zone, or to be frangible or are provided with an adequate shield (e.g. road safety barrier, crash cushion) to protect errant drivers.

4.3 Design Step D2: Identify Hazards

4.3.1 General

Austroads *Guide to Road Safety – Part 9: Roadside Hazard Management* (Austroads 2008c) discusses the types of roadside hazards that may occur in the context of providing a forgiving roadside environment. A roadside hazard is an object or feature located between the edge of traffic lane and road reserve boundary, or within a median, that could cause significant personal injury (including fatal injury) to vehicle occupants when impacted by an errant vehicle.

For the purpose of hazard identification, the types of hazard that may be encountered in roadsides include:

- embankments and cuttings
- roadside objects such as trees and poles
- culvert ends
- non-traversable open drains
- bodies of water
- road safety barriers
- oncoming traffic.

Step 2 in the hazard mitigation process involves the identification of all roadside hazards within the clear zone and consideration of high-risk hazards beyond the clear zone. The road designer should identify and list all roadside hazards within the area of interest (based on clear zone widths) using Table 4.3 as a guide. It should be noted that road safety barriers are classified as hazards despite the fact that their sole purpose is to prevent a vehicle from encountering a more severe hazard.

It is important to understand that whilst a safety barrier is effective in shielding severe hazards, the barrier will be longer and closer to the road than the hazard it is shielding. Therefore, the barrier will have a greater probability of being impacted and the number of crashes is likely to increase even though there is a net road safety gain because of reduced severity of impacts.

For existing roads crash histories for particular sites or lengths of road should be considered in the identification of roadside hazards. Further information is provided in Commentary 4.

4.3.2 Types of Hazards

A summary of the more common types of hazards that may exist adjacent to roads is provided in Table 4.3. A variety of fixed hazards may occur in roadsides and hazards may also be regarded as ‘point’ hazards or ‘continuous’ hazards as shown in Commentary 5.

For the general purpose of this guide the following objects are not considered to be hazardous fixed objects for vehicle occupants:

- small size steel and timber sign support posts that comply with AS 1742.2 – 2009, Table D2 and Table D3
- slip-base poles and frangible posts
- objects located beyond the deflection area of a safety barrier
- trees ≤ 70 to 100 mm diameter (depending on the species) at their base
- tubular thin-walled traffic signal posts at urban intersections.

Whilst these objects may not be hazardous to vehicle occupants they are likely to be hazardous for errant motorcyclists and therefore the number of poles adjacent to roads should be minimised and their design made as forgiving as practicable. In addition, the presence of these objects may cause an errant driver to take evasive action in order to avoid them and this may lead to a more serious crash.

In practice many traffic signal poles are not frangible and are not protected. The reason for this is that these poles require adequate strength to support the necessary traffic signal and road lighting hardware, particularly under wind loading, and the provision of barriers to shield the poles is usually impracticable or would lead to other disbenefits. Most importantly, traffic signal systems provide significant net road safety benefits.

Table 4.3: Summary of roadside hazards

Hazard	Comment
Other vehicles	Where the area of interest (as defined by clear zone widths) includes one or more opposing lanes of traffic, the danger of errant vehicles crossing the median and colliding with oncoming or stationary vehicles is high. This issue also applies to special facilities that are accommodated in a median or a separate reservation adjacent to the road. Such facilities may include: • a high occupancy vehicle lane • local traffic (e.g. frontage roads) • traffic adjacent to the through traffic where there is a speed differential equal to or greater than 20 km/h • transit corridors (e.g. busways, railways, light rail etc.) • freight railways. These facilities may require a safety barrier to separate their operations from an adjacent road carriageway. For example, transit corridors or freight railways within or adjacent to intermediate or high speed roads are typically protected with an appropriate safety barrier unless a comprehensive risk assessment demonstrates that protection is not required. Consideration needs to be given to not only the risk to motorists but also to users of the transit corridor or the freight railway.
Fill batter	Fill batters may be hazardous due to the combination of height and slope and surface condition, as well as what may be on the slope or at the base of the embankment. They become critical when the slope exceeds 3:1 as vehicles are likely to overturn. A warrant for treatment of fill batters on high-speed roads is shown in Figure 4.6 and an embankment assessment process is described in Section 4.3.4.
Cut batter	Cut batters may be hazardous due to the combination of height, slope and surface. Slopes steeper than 4:1 may cause an errant vehicle to become unstable and rough surfaces (e.g. jagged rock) may also cause vehicle instability and excessive damage to the vehicle.
Non-frangible objects (such as bridge piers, bridge end posts, concrete barrier end-on impact, rock face cuttings, large items of built environment infrastructure, etc.)	Non-frangible objects are hazardous when: they are too close to the travelled path piers are unshielded in the median reserve snagging on an exposed face does not allow the vehicle to slide along the structure.
	Retaining walls may be hazardous depending on the type, height and lateral location with respect to traffic. Surface texture of the walls and treatment of the end of walls can also be hazardous to errant vehicle occupants.
	Rock cuttings are hazardous when: • a steep-sided slope is more than 4:1 • there is a steep-sided or a deep ditch at the foot of the slope • the height is less than 1.5 m above travelled path level • they are close to the travelled path • there are unshielded rock excavations and exposed rock cuts • there is a rough surface with irregularities of more than 65 mm, even though the face may be in an even plane (refer to Section 5.4.8).
	Steel or concrete bridge parapets are hazardous when: • the upper railing is not designed for absorption of car crashes • terminations are not protected.

Hazard	Comment
	Buildings and walls are hazardous when: • they are too close to the travelled path • the exposed angle of the property wall or the wall itself blocks the errant vehicle.
Trees, poles and vegetation	Trees, poles and vegetation are hazardous when they are large and too close to the travelled path. Trees are particularly dangerous when: • the diameter is more than 70 to 100 mm (depending on species) • fallen branches are left aside the travelled path • tree stumps are more than 100 mm over ground level.
	The problems associated with forests and groups of close-spaced trees depend on the spacing of the trees and thus influence the type of safety measures required.
	Many items of road furniture rely on break away or energy-absorbing structures to protect errant vehicles. Road furniture items considered to be potential hazards are: • utility poles (power, telephone overhead cables) and high-voltage electricity columns • sign supports, including vertical sign supports, sign gantry legs, posts of large signs and overhead sign supports, traffic sign supports • steel and high-mast lighting columns, lighting poles and luminaire supports • rural mailboxes and structures • any non-yielding pole.
	Vertical sign supports, traffic signs, posts of large signs, sign gantry legs and lighting columns are dangerous when: • the structure is not yielding when hit • lighting columns are close to the travel lanes • lighting columns are on medians.
Culverts	Cross drainage of road reserves is achieved by the provision of culverts that may vary in size from a single small pipe (e.g. 375 mm) to large multiple pipes or box culverts. Culverts that do not have their inlet and outlet matched to a traversable foreslope are a hazard. If not treated single culverts and end treatments wider than 1.0 m are a hazard for passenger size vehicles. Untreated large culverts (i.e. ends not matched to foreslope and no grates over openings; single pipe > 900 mm diameter, multiple pipes > 750 mm diameter) within the clear zone are a hazard and should be assessed taking into account factors such as the: • volume of traffic • height of drop associated with the culvert • culvert size • distance and pavement slope between the headwall and the edge of traffic lanes. Untreated culvert ends at right angles to the direction of traffic are a hazard, for example, culverts under driveways or median crossings.
Culvert headwalls	Culvert headwalls are hazardous when they are: • too close to the travelled path • not matched to embankment foreslope • higher than 100 mm • mounted into the drain beside the travelled path.

Hazard	Comment
Drains and kerb	Acceptable longitudinal open drain profiles are described in Section 4.6 of the Guide to Road Design – Part 3: Geometric Design (Austroads 2009b). However, some crash testing of drain shapes indicates that, depending on the angle, shapes outside of those described in Part 3 are traversable (Thomson & Valtonen 2002); refer also to Commentary 6 for more information. As a general guide, longitudinal drains and kerbs are hazardous where: • foreslopes have gradients 3:1 or steeper • if the foreslope and the backslope (2:1) form a V-shape, as it is possible to crash into the back slope • they are located at the foot of a fill slope • there is an object with high-severity attributes located in the drain • the kerb shape and height is not appropriate for the speed environment and may affect the performance of the roadside infrastructure installed behind it. Transverse open drains are usually provided outside of the road formation to carry water into culverts and unless designed correctly with a suitable cross-section, they may also present a hazard to vehicle occupants. In addition, less than 0.3 m of water in a traversable drain shape may make the drain non-traversable, particularly for light cars.
Road safety barriers	Road safety barriers should be regarded as hazards in that they are roadside objects which may be impacted by errant vehicles. They should only be used where they constitute a lesser hazard to road users than the hazard being shielded. There are increased risks associated with barriers when: • the vehicle crashes against an inappropriate barrier (e.g. barrier not suited to site constraints, improper dimensions, poor positioning or untreated terminations) • the vehicle crashes against improperly maintained road safety barriers • vehicles can move behind the road safety barrier • the distance between the barrier and the hazard is less than the working width of the barrier when impacted, allowing the vehicle to deform the barrier and contact the hazardous features • the height of the barrier is too low • the length of need is not adequate • the barrier is too short • the length of anchorage is too short • there is a short gap between two barriers • they are too high and limit sight distance • a gating end treatment is installed without a hazard-free run-out area • the barrier effectiveness is reduced due to terrain effects, kerbing, drains etc. • penetration of a lower test level barrier occurs when it is impacted by a vehicle that is larger than the test vehicle.
	Motorcyclists are likely to be injured when hitting road safety barriers and barrier delineators.
	Road safety barrier terminals can be dangerous when: • the termination of the barrier is not properly anchored • the distance between the obstruction and the barrier terminal is too short • the transition between deformable and rigid barriers causes high deceleration • they do not meet performance class requirements.

Hazard	Comment
Bodies of water	Bodies of water should be evaluated with respect to the degree of potential hazard they pose (NYS DOT 2003). This will be a combination of the amount of water and its accessibility. The depth of water may be ranked according to whether: • a vehicle can completely submerge, resulting in the drowning of uninjured non-swimmers, disabled or elderly persons, or infants (depth of water > 0.6 m) • water could fill an upright car to a point where an unconscious or injured driver or passenger would drown (typically assumed to be a depth of 0.6 m) • an upside down car would be in water deep enough that an unconscious person would drown (a depth of 0.3 m). Fast-moving bodies of water are considered to be more hazardous than still water. In general, designers should carefully consider the risk associated with bodies of water over 0.6 m deep, or water courses with a normal base flow depth greater than 0.6 m, as these could cause a stunned, trapped, or injured occupant to drown. Other factors to consider include the: • slope of the vehicle path to the water • total distance available in which to stop a vehicle • likelihood of a vehicle being upside down upon reaching the water • persistent or intermittent presence (flooding potential) of the water hazard • presence of intervening obstructions that would reduce the likelihood of an errant vehicle reaching the water.

4.3.3 Embankment Warrant for High-speed Roads

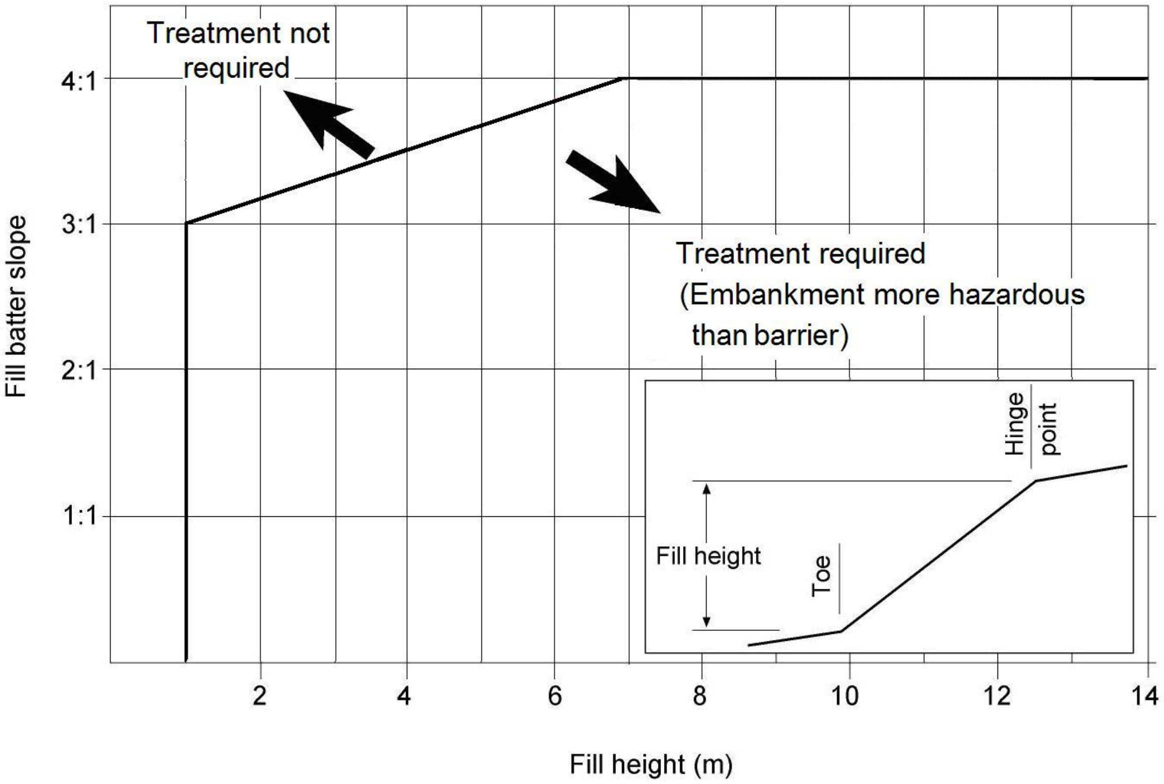
Figure 4.6 provides a warrant for treatment of an embankment on intermediate-speed (i.e. 70 to 90 km/h) and high-speed (i.e. > 90 km/h) roads with a traffic volume greater than 2000 vehicles per day. The treatment may include embankment flattening or the installation of a suitable road safety barrier system. Short sections of embankments exceeding the warrant (lengths less than the minimum length of barrier) should be flattened rather then being treated with a barrier.

For lower traffic volumes and low-speed roads (≤ 70 km/h) the risk that such embankments pose should be assessed on a site-by-site basis using a risk assessment and a benefit-cost analysis approach.

It should be noted that Figure 4.6 is based on the relative severity of the embankment versus a W-beam barrier and assumes that the slope is smooth and firm. When assessing the hazard that an embankment poses to the road user the surface condition of the embankment should be considered. Appendix E lists five classifications (types A to E, see notes to Table E 1) of surface conditions and the severities relating to them (AASHTO 1996) as well as severities for different types of barrier. These severities can be used to assess the need for treatment where the conditions differ from those on which Figure 4.6 is based. In such cases the embankment assessment process illustrated in Figure 4.7 may be used.

It should be noted that the type A condition is typically what would result following the construction of new embankments and types D and E might be applicable at sites where rock protection is proposed (e.g. at bridge sites). Types B and C are more applicable for existing embankments and should therefore be used in assessing existing embankments.

Figure 4.6: Embankment warrant for intermediate-speed and high-speed roads



Note:

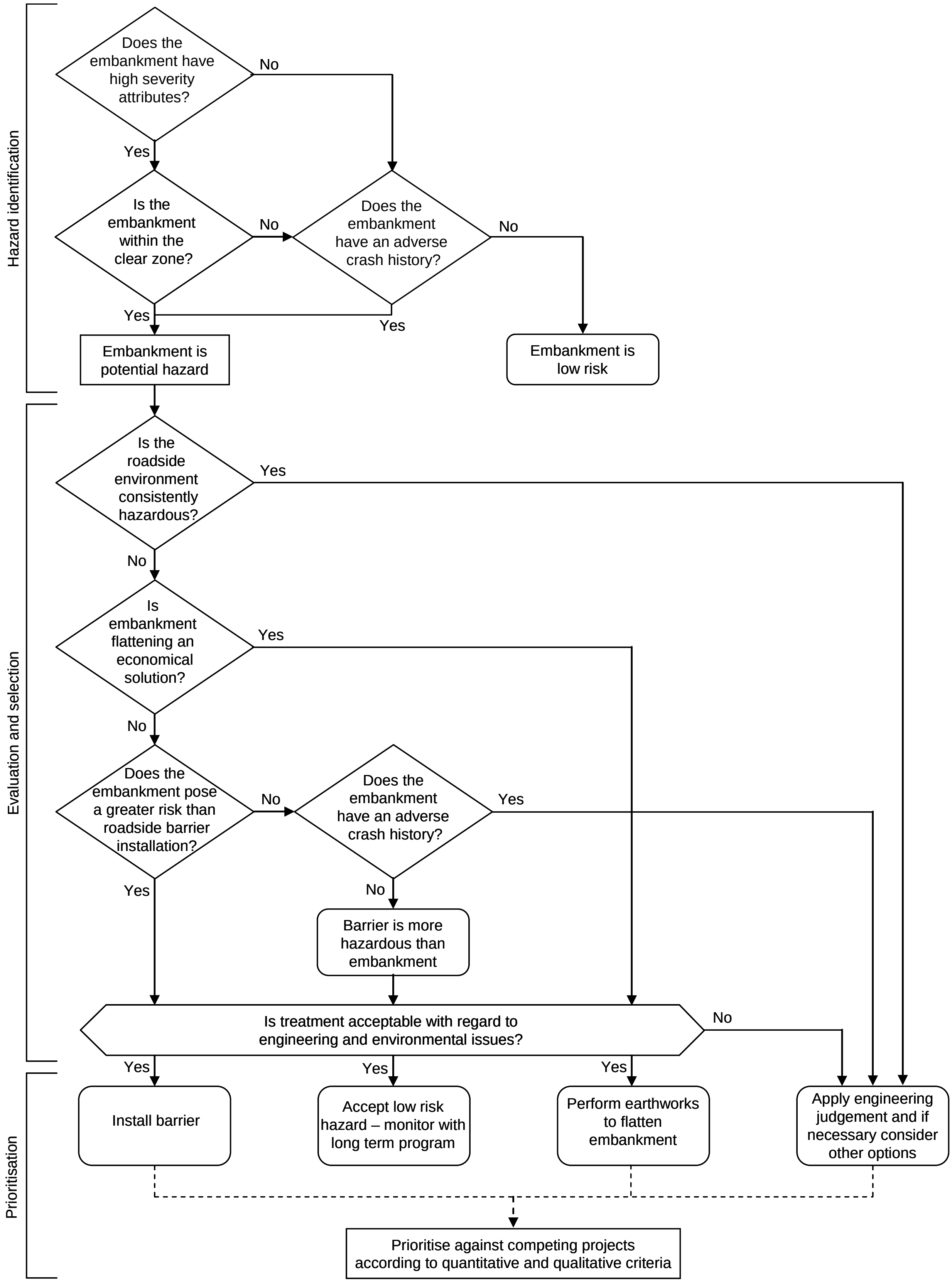
Based on a graph of severity indices against embankment height for a foreslope of 3:1, assuming that batters are smooth and firm in all seasons (Table A.13.1 of AASHTO 1996). Severity index of embankment at about 1 m high is approximately the same as W-beam barrier for slope of 3:1.

This figure does not consider the likelihood of vehicles encroaching onto the batter and is based only on the severities of the embankment and barrier.

4.3.4 Embankment Assessment Process

Figure 4.7 illustrates a process for the assessment of embankments to determine whether they are a potential hazard. This process should be used for more detailed assessment of embankments and particularly where the circumstances differ from those on which Figure 4.6 is based. The quantitative economic analysis referred to in the figure should preferably be undertaken using software such as RISC or RSAP (AASHTO 2003) described in Sections 4.5.7 and 4.5.8 respectively. Table 4.4 summarises considerations relating to key questions in Figure 4.7 and the application of the process will lead to one of the possible conclusions summarised in Table 4.5.

Figure 4.7: An example of an embankment assessment process



Source: Based on QDMR (2005).

Table 4.4: Consideration of embankments

Question	Consideration
Does the embankment have high severity attributes?	High severity crashes with embankments are primarily due to vehicle rollover. Factors that are considered to contribute to the likelihood of vehicle rollover include: • Embankment (fill) slopes – batter slopes between 4:1 and 3:1 are traversable but too steep for a driver to recover, and a slope of steeper than 3:1 is critical as the errant vehicle is likely to overturn. • Embankment height – the likelihood of vehicle rollover with a high severity outcome increases significantly where the embankment height exceeds 1.5 m and embankment slopes are critical. • Ground conditions on the embankment – the probability of vehicle rollover is increased if there is a likelihood that the vehicle’s tyres will dig into the ground or the vehicle will strike a surface irregularity (e.g. large rocks, sharp mounds or depressions) which could trip the vehicle. • Absence of rounding at gradient changes of roadside terrain – rounding should be applied at gradient changes (hinge points) as it provides drivers with a greater opportunity to maintain or regain control of the vehicle and decreases the likelihood of rollover by preventing the vehicle from achieving large values of angular momentum about the longitudinal roll axis. • Embankment slopes should be no steeper than 4:1, as drivers who encroach onto such slopes have a greater chance of safely bringing their vehicle to a stop or controlling it down the slope. In order to cater for the different characteristics and performance of heavy commercial vehicles, embankment slopes of 6:1 or flatter are desirable where this can reasonably be achieved, particularly where truck volumes are high.
Does the embankment have an adverse crash history?	It is recommended that any roadside object or location that has at least three casualty crashes or crashes where vehicles are towed away within a five-year period be considered for remedial treatment, regardless of other factors (e.g. lateral offset and/or traffic volume). However, threshold values for the consideration of treatments may vary between jurisdictions and specific programs.
Is the roadside environment consistently hazardous?	In some situations the application of these guidelines may not be practicable, for example in situations where traffic volumes are low, or speeds are restricted by road alignment (e.g. mountainous terrain), and a consistent road environment exists with potential hazards at a uniform offset but within the computed clear zone. The combination of a low number of likely encroachments into the roadside and the high cost of continuous road safety barrier may mean that the installation of road safety barrier is not justified. Analysis of crash data has indicated that the frequency of crashes tends to increase at the interface between varying types of road environment, or inconsistent segments of road. An example of this is the first tight curve after a long straight section of roadway. For the reasons outlined above it is suggested that the following process be applied to roads that potentially have a consistently hazardous roadside along their length, and the provision of continuous road safety barrier is not justified: • ensure that signing and delineation is of a high standard that meets current guidelines to provide drivers with an adequate indication of road alignment • ensure that the road surface and shoulders are adequately maintained • provide road safety barrier (if justified based on embankment/hazard attributes) at the interface between road segments of different horizontal alignment standards • monitor crash data to identify any particular locations where a road safety barrier may be justified.
Is embankment flattening an economical solution?	A preferred option to the installation of road safety barrier is slope flattening to 4:1 or flatter. American research has shown that this can result in a significant reduction in the severity of vehicle run-off-road crashes, which is primarily due to the reduction in probability of vehicle rollover. An economic evaluation of flattening the embankment, compared to installing road safety barrier, may be undertaken. This should include the costs associated with crashes, maintenance and installation for each option.

Question	Consideration
Does the embankment pose a greater risk than road safety barrier installation?	This involves a comparison of the risks associated with retaining an unshielded embankment with those relating to road safety barrier installation. The risk assessment should consider: • whether all hazardous objects located on or at the toe of the embankment have been considered • if there are other possible severe consequences of a vehicle encroaching onto the embankment and beyond, other than damage to the vehicle and its occupants • whether the road provides for a higher function than that indicated by the AADT. • Engineering judgement is then required to determine if the road safety barrier is justified.

Source: Based on QDMR (2005).

Table 4.5: Summary of conclusions from embankment assessment process

Possible conclusions	Consideration
Embankment is low risk	As the embankment has low severity and/or is located such that impact is unlikely, no further analysis is required for this situation. Monitoring of the crash database and road environs should be undertaken to identify any change in circumstances over time. Note that although the risk is low, this does not mean that the object is not a hazard to an errant vehicle. The level at which the risk changes from acceptable to unacceptable is difficult to quantify and subject to debate.
Flatten embankment	Given that the installation of a road safety barrier introduces a new object into the clear zone, it is desirable to flatten the embankment such that it does not pose a hazard to an errant vehicle.
Embankment is more hazardous than road safety barrier	Installation of road safety barrier or some other type of treatment is recommended because the embankment is determined to be more hazardous than road safety barrier.
Road safety barrier is more hazardous than embankment	The installation of a road safety barrier is considered to be more hazardous than the untreated embankment. Installation of road safety barrier is not recommended.
Apply engineering judgement and if necessary consider other options	The installation of a road safety barrier may not be recommended; however, if required a more detailed assessment may be undertaken and may yield other suitable treatment options.

Source: Based on QDMR (2005).

4.3.5 High-consequence Hazards

Roadside hazards

To design for more than the 85th percentile speed requires a much greater clear zone distance and a wider area of interest beside the road and hence the cost of providing a road is considerably more, for even the most modest percentile increase. Therefore, the incremental risk reduction afforded by increasing the width of the area of interest does not generally warrant the expense. This argument is based on collision frequency grounds and assumes that, in general, hazards outside the errant vehicle recovery zone are of the same nature, and present the same consequences, as those within the area of interest. However, there are circumstances when the potential consequences of a hazard outside the area of interest are particularly severe and the risk should be managed.

Where a roadside hazard presents particularly high consequences, consideration should be given to the identification and subsequent assessment of hazards beyond the calculated clear zone width. Schoolyards, cliff drops, fuel storage facilities and transmission towers close to the road are examples where further consideration should be given. In addition, where a road is known to have a high concentration of buses or coaches, consideration should be given to the identification and assessment of hazards outside the area of interest.

Similarly, at locations where the frequency of collisions is believed to be considerably above average, for example where historical data provides evidence of a high crash rate, hazards outside the recommended area of interest may need to be assessed.

Opposing vehicles and medians

Other vehicles travelling on the road (particularly those travelling in the opposite direction) present a significant hazard to errant vehicles. On two-lane, two-way roads, head-on collisions are usually of high severity due to the combined speeds of the two vehicles.

Collisions with vehicles travelling in the opposite direction have also occurred on duplicated roads that have substantial medians (e.g. even > 20 m) usually with very severe outcomes. Because of the high consequences some road authorities therefore choose to prevent cross-median crashes on some sections of high-volume, high-speed duplicated roads, particularly those that have a high proportion of heavy vehicles. Guidelines for the provision of barriers to protect drivers from severe cross-median crashes may vary between jurisdictions and therefore designers should refer to relevant road authority policy and guidelines.

4.4 Design Step D3: Identify Treatment Options

Where hazards exist within the area of interest (or outside the clear zone in the case of high-consequence hazards) potential treatment options should be identified so that their effectiveness in reducing the risk associated with the hazard can be assessed.

The following basic options should be considered (listed in order of priority):

- removal of the hazard
- relocation of the hazard to a position where it is less likely to be struck (ideally as far from the road as possible)
- provision of a roadside that assists the driver to control the vehicle once it has left the road in order to avoid the hazard
- reduction of the impact severity posed by the hazard (e.g. re-design so that a hazardous feature can be safely traversed, use of frangible poles etc.)
- shielding the hazard with a longitudinal barrier or crash cushion
- delineation of the hazard if the risk and severity is low and the above alternatives are not appropriate.

Improvements to delineation should always be considered in addition to other risk mitigation options. In addition consideration may be given to:

- roadway improvements
- changes to the scope or budget of the project
- accepting that the risk of the untreated hazard where the risk of hitting the hazard and severity are both low, but recognising it as a hazard that should be monitored within a long-term program.

The possibility of changing the scope of the project or the budget available, particularly if the options being considered have limitations in terms of their effectiveness, should be considered when deciding on the options. A change in the scope or budget may enable the consideration of more effective options that could not be contemplated within the initial scope and budget.

Treatment options are discussed in Section 5.

4.5 Design Step D4: Evaluation of Treatment Options

4.5.1 General

Once a potential hazard has been identified (refer to Sections 4.2 and 4.3) an assessment of the hazard and treatment options is undertaken which can include a quantitative assessment and a qualitative assessment, the latter being based on the suitability of the treatment option in relation to social, environmental and other factors. For example, treatment options need to be evaluated for effectiveness and feasibility and issues that need to be considered include:

- risk reduction
- cost
- environmental impact
- time to implement
- constructability
- aesthetics.

Any viable hazard treatment option should be considered when assessing the management of a hazard. Treatment options should include those that reduce the frequency of impacts with any object or reduce the consequences when an impact occurs.

The evaluation process may result in a number of viable treatment options from which a treatment may be chosen. Some possible treatment options, including those that may be an alternative to the installation of road safety barrier, are listed in Section 4.4 and discussed in more detail in Section 5.

The quantitative methods used for more detailed investigation of hazards and treatment options involve an economic analysis of the crash costs associated with retaining a hazard compared to the reduction in crash costs and whole of life costs associated with treating the hazard. This is essentially a benefit-cost analysis of roadside hazards and treatments, similar to analyses undertaken for other road projects. The *Guide to Project Evaluation – Part 2: Project Evaluation Methodology* (Austroads 2005) provides guidance on the evaluation of projects including the theory relating to calculation of benefit-cost ratios.

4.5.2 Quantitative Assessment

A quantitative evaluation includes an assessment of the risk associated with hazards and computation of an annual cost of crashes. The same method can be used to analyse the risk and determine annual crash costs associated with treatment options. This information can then be used together with installation, construction and maintenance costs to undertake benefit-cost analysis.

However, simply having a benefit-cost ratio greater than unity may not be justification for the construction of a roadside safety treatment. Each project must compete with others for limited safety funds. The *Guide to Road Safety – Part 8: Treatment of Crash Locations* (Austroads 2009a) provides information on justifying expenditure on road safety projects, the economic appraisal of projects and also provides estimated crash reduction factors for various treatments.

Quantitative evaluation uses numerical values for both the likelihood of a run-off road crash occurring and the consequences of the crash and is suited to more complex situations. Consequences may be determined by modelling the outcomes of an event or set of events, or by extrapolation from experimental studies or past data (AS/NZS 4360 – 2004). In dealing with run-off road crashes the process typically involves a hazard risk assessment using encroachment factors and severity indices in conjunction with other information to quantify the events (refer to Section 4.6)

The severity indices are related to crash costs to enable benefit-cost analysis that estimates the benefits derived from a specific course of action compared to the costs of implementing that action. If the estimated benefits of a specific design exceed the cost of constructing and maintaining that design over a period of time, the safer design may be implemented.

The primary benefit obtained from selecting one design over another is the expected reduction in future crash costs. These include property damage costs, personal injury costs and fatality costs. In some cases, the total number of crashes may be reduced by a given treatment, such as providing a significantly wider roadside recovery area than previously existed. In other instances, the safety treatment may not reduce the total number of crashes but may reduce their severity (e.g. the installation of a barrier).

4.5.3 Qualitative Assessment

Before a treatment option is selected for prioritisation and implementation, its suitability in terms of environmental and engineering factors should be considered.

Environmental considerations

The environmental issues that require consideration include:

- recognition of unique vegetation (e.g. environmentally sensitive areas or national parks). If the clearing of trees within the clear zone is unacceptable on environmental grounds, alternative treatment options will have to be considered
- the retention of water courses in their natural state adjacent to the road
- reduction of clearing
- visual pollution.

Engineering considerations

The engineering factors that require consideration include:

- traffic growth
- pedestrian and cyclist traffic (including children)
- vehicle mix including motorcyclists
- crash history
- other geometric influences
- social justice/equity
- road is used as a school bus route
- access requirements
- road is used as a freight route.

Sites that have a crash history need to be evaluated such that an appropriate priority for treatment can be assigned. Other examples are school bus routes or freight routes that pass close to schools and generate high numbers of young pedestrians who may require a higher level of protection (e.g. separation from the road or shielding).

4.5.4 Methods for Quantitative Analysis

There are six methods that may be used to undertake a quantitative assessment of the risk associated with a hazard and the appropriate treatment for a hazard. Jurisdictions in Australia and New Zealand may use one or several of these methods depending on the complexity of the hazards alongside the section of road that is being investigated.

Similar basic principles are applied in all the methods in that they have the objective of minimising the number of crashes and the severity of crashes. Most methods involve an economic analysis. However, the methods vary in the extent of analysis and the details of the analysis. A related product is the Road Safety Risk Manager, a product developed by ARRB that is described in Commentary 7.

The methods available are:

- a simple manual method
- a detailed quantitative manual method
- the Roadside Incident Severity Calculator (RISC program) developed by the Queensland Department of Transport and Main Roads
- the Roadside Safety Analysis Program (RSAP) that is the current USA method developed through the National Cooperative Highway Research Program (AASHTO 2003)
- a method developed by RTA that calculates the risk associated with a hazard and compares it to an intervention benchmark for the particular type of road.

4.5.5 Simple Manual Method

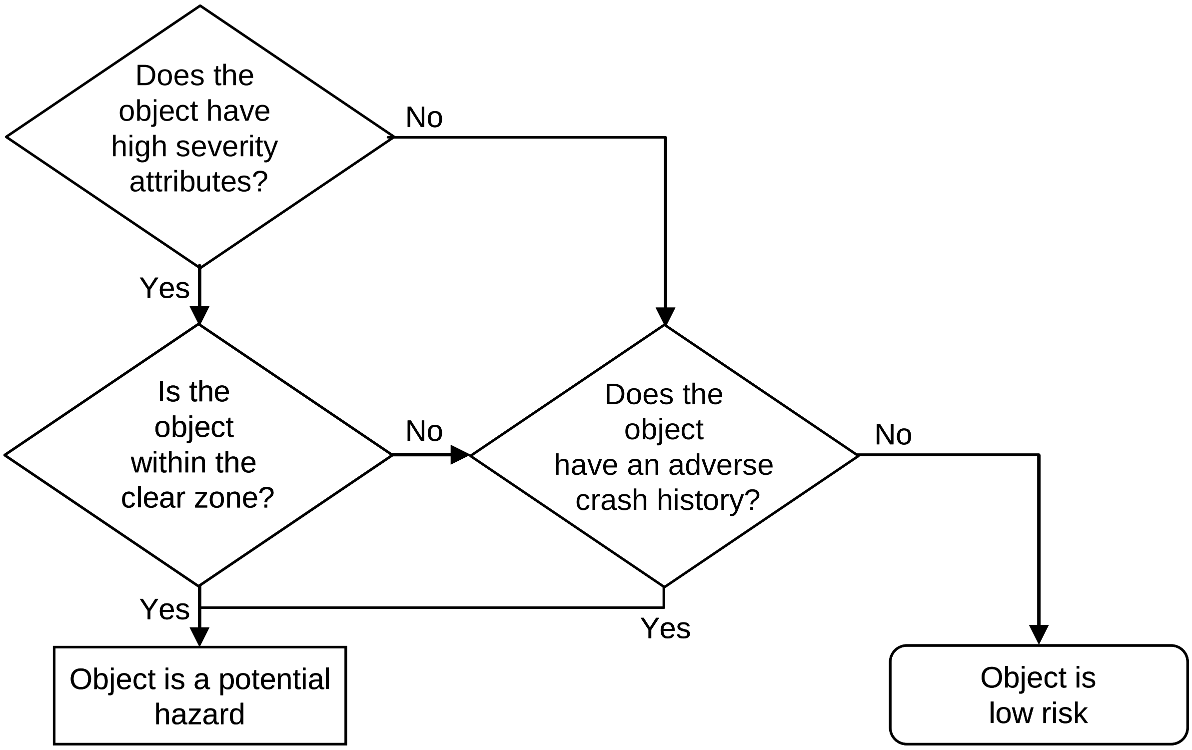
In circumstances where a hazard exists beside the road a simple procedure may suffice to determine whether the hazard requires treatment. The method involves:

- An assessment of the likelihood that a vehicle will crash into an object or feature and the severity of the crashes.
- An assessment of the number of crashes that would occur with a treatment and the severity of those crashes.
- A comparison of the number and severity of crashes that would occur at an untreated hazard with the number and severity of crashes if a treatment was provided (e.g. road safety barrier).

The process shown in Figure 4.8 involves:

- An assessment as to whether the object or feature has high severity attributes requiring consideration of the severity of the object (refer to Section 4.6.3 and relevant tables in Appendix E).
- Confirmation that the object lies within the clear zone (Table 4.1).
- A check of the jurisdictional crash database to establish whether the object has an adverse crash history.
- An assessment of the likelihood that an errant vehicle will reach the object (Figure 4.12).

Figure 4.8: Simple process for risk assessment



Source: Based on QDMR (2005).

4.5.6 Detailed Manual Method

The detailed manual method is based on a risk assessment and economic analysis as discussed in Section 4.5.2 and Section 4.6.

The process involves:

- From crash data for an existing situation or from the process in Section 4.6, determine the annual crash cost for the hazard.
- Using the guidance in Section 5 and Section 6 develop options for treatment of the hazard.
- Estimate the costs associated with each treatment option including crash costs (e.g. crashes into a road safety barrier), construction costs, annual maintenance costs and operating costs where applicable. Note that the process in Section 4.6 can be used to establish crash costs associated with treatments that have some risk for road users. An example of the calculation of crash costs associated with a hazard compared to a road safety barrier is provided in Appendix F.
- A benefit-cost analysis of the whole of life costs should then be undertaken of the existing situation (i.e. the untreated hazard) and of all treatment options identified for evaluation and consideration. This process is described in Section 4.5.1 and Section 4.5.2. Refer also to the *Guide to Project Evaluation – Part 2: Project Evaluation Methodology* (Austroads 2005).
- Use the results of the benefit-cost analysis in conjunction with any qualitative analysis (Section 4.5.3) to establish which treatment should be recommended.

4.5.7 Roadside Impact Severity Calculator

The Roadside Impact Severity Calculator (RISC) is a program developed by the Queensland Department of Transport and Main Roads based on the AASHTO software ROADSIDE and is used to perform quantitative evaluation of hazardous roadside objects.

RISC requires the user to model roadside objects and potential treatments for these objects using an array of numerical parameters. Once this is done the relative benefits and costs for different treatments are automatically calculated using an algorithm based on the AASHTO *Roadside Design Guide* (AASHTO 1996). The most cost-effective treatment for each hazard can be determined and the decision making process can then continue to the next step. The program operates through a series of windows and menus.

The modelling can be used to determine the possible benefit-cost ratios achievable by comparing the treatment options available. For example, a comparison can be made between leaving an end-on culvert as it is, installing bar grates, redesigning the end wall to reduce its severity, and the installation of a road safety barrier.

The method and processes adopted by the RISC software for determining the impact frequency of errant vehicles and calculating crash costs is outlined in Appendix G.

4.5.8 Roadside Safety Analysis Program

The Roadside Safety Analysis Program (RSAP) software is described in Appendix A of the *Roadside Design Guide* (AASHTO 2006; Amendment Chapter 6 – median barriers 2006). The information in the appendix advises that RSAP was developed under the National Cooperative Highway Research Program Project 22-9 (AASHTO 2003) and represents one approach to using the *Roadside Design Guide*. In addition, in reference to RSAP it is stated that:

> *It carries no guarantees or warranties from the American Association of State Highway and Transportation Officials. The RSAP program is intended as a tool for economic analysis and should not supersede the guidelines presented in the Roadside Design Guide or sound engineering judgement.*

This condition seems to correctly suggest that RSAP is a tool and practitioners who use it should understand how it operates and be responsible for the data used and the results it generates. Like all software, used appropriately RSAP is considered to be a useful tool that could be utilised by Australian and New Zealand jurisdictions.

RSAP was developed because deficiencies were identified in previous AASHTO software entitled ROADSIDE, and as a result of the Federal Highway Administration (FHWA) adopting the NCHRP Report 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* (Ross et al. 1993), as the official guidelines for safety performance evaluation of highway features. As a result, RSAP provides an improved computer-based cost-effectiveness analysis procedure for use in:

- assessing alternative roadside safety treatments at both point locations and for sections of roadway
- developing warrants and guidelines including those which consider performance levels of safety features.

RSAP provides a simple and structured means for data entry and four separate reports summarising the analysis results and input data, namely:

- Benefit-cost ratio – Presents the incremental benefit-cost (b/c) ratios associated with the alternatives in a tabular format for all combinations of alternatives (e.g., alternative 1 to alternative 2, alternative 2 to alternative 3, and alternative 3 to alternative 4, etc.). It should be noted that the alternatives are re-arranged in ascending order of direct cost (i.e. the direct cost of each alternative is higher than that of the previous alternative) so that the denominator of the b/c ratio will not be negative.
- Alternative cost – Presents the predicted crash frequencies, and the annual installation, maintenance, and repair costs associated with each of the alternatives in a tabular format.
- Feature cost – Presents the predicted impact frequencies, average severity, and crash costs associated with individual features of each alternative in a tabular format.
- Input data – Presents the input data for each alternative in a summary form.

4.5.9 Alternative Crash Risk Method

An alternative crash risk method that may be considered generally follows the same process as the hazard risk assessment that is shown in Figure 4.10 except that a different approach is taken beyond Step R1g as shown in Figure 4.9, namely:

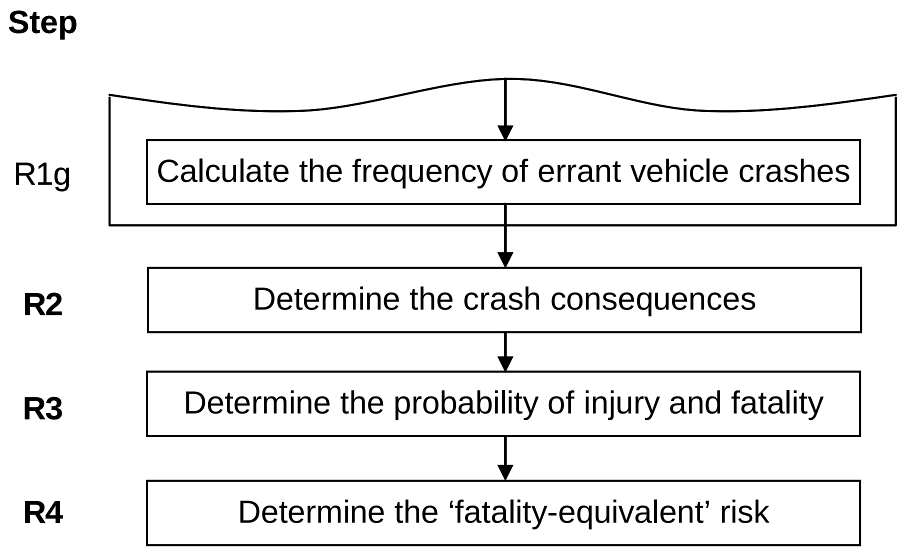
Step R2 – Determine the crash consequences

The crash consequences (another term for severity) are determined from a suite of tables similar to those described in Section 4.6.3 and presented in Appendix E that provide crash consequence indices for various roadside features and objects.

Step R3 – Determine the probability of injury and fatality

This step involves the use of a table that relates the crash consequence indices to the probabilities of injury or fatality. The values from the table are used as an input to Risk Step R4.

Figure 4.9: Part of the alternative crash risk assessment process



Note: This process is an alternative approach beyond Step R1g in Figure 4.10.

Source: Adapted from RTA (2008).

Step R4 – Determine the risk

The risk of injury and the risk of fatality are calculated separately. The risk of injury is divided by a factor of 14 to reflect the difference in injury crash costs and fatality crash costs. This allows for the lesser magnitude of injury consequences to be compared with those leading to acute injury or fatality. The risk of fatality per crash is multiplied by the number of crashes per year and the combined risk level of the hazard or treatment option is calculated as follows:

$$Risk_{(combined)} = \text{crashes per year } (N) \times [risk_{(injury)} / 14 + risk_{(fatality)}]$$

The combined risk is then compared to a benchmark for the type of road to determine the required action. If the combined risk is below the benchmark, consideration is given to the consequences of leaving the hazard as it is, and if it is greater than or equal to the benchmark treatment options are considered. Designers should refer to RTA (2008) and the Roads and Traffic Authority NSW for further information.

4.6 Hazard Risk Assessment

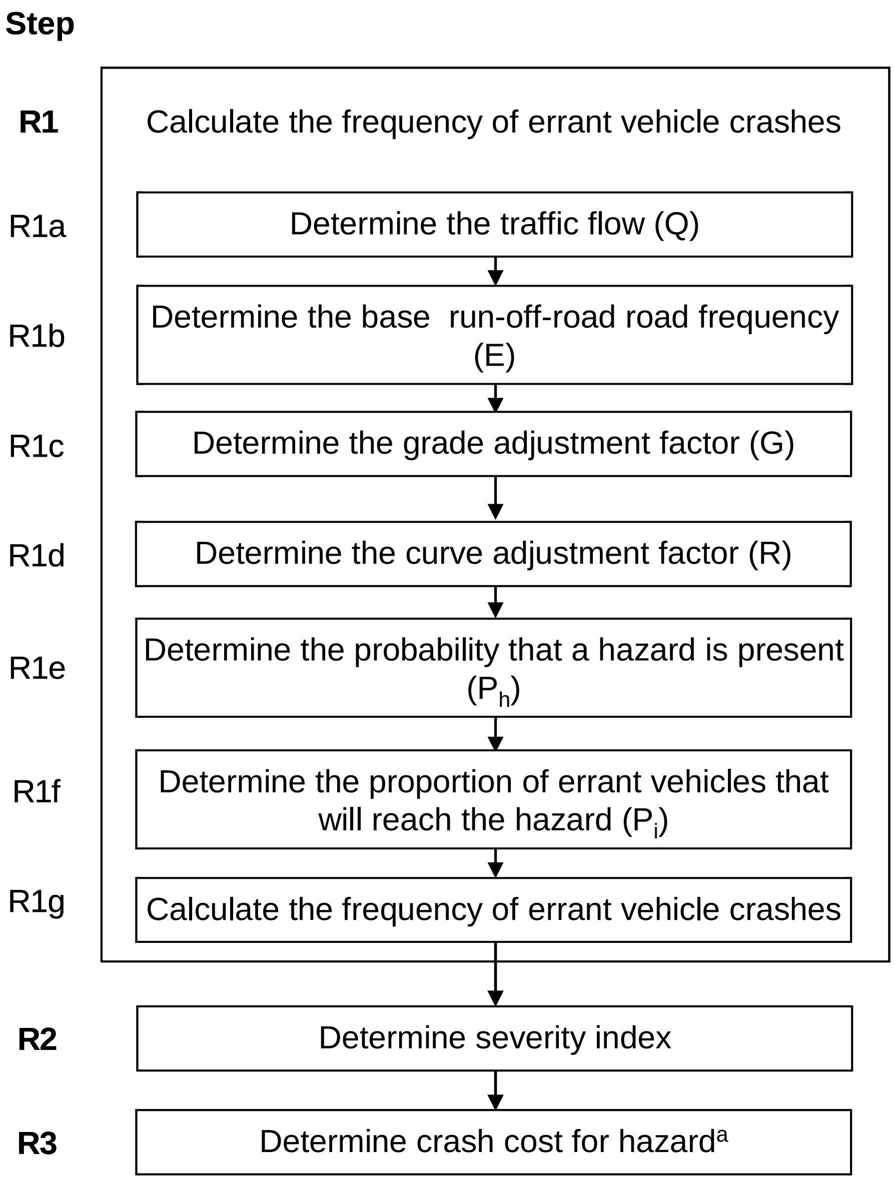
4.6.1 General

The quantitative evaluation process used by various road authorities and computer programs is similar but the detail of some parameters may vary to suit the requirements of the authority. The methods involve a hazard risk assessment and a typical process should include:

- Risk Step R1 – calculation of the frequency of errant vehicle crashes
- Risk Step R2 – consideration of the severity of the crashes with the hazard/s
- Risk Step R3 – comparison of the results for a hazard with those for a treatment (or a benchmark in the case of the RTA NSW).

Figure 4.10 shows a process to determine the frequency of errant vehicle crashes. It involves steps that are in the following sections.

Figure 4.10: Risk assessment process based on frequency and severity of errant vehicle crashes



Note: RTA (2008) determines the probability of injury or fatality and a combined risk at this stage in the process.

Source: Adapted from RTA (2008).

4.6.2 Risk Step R1 – Calculate the Frequency of Errant Vehicle Crashes

The frequency of vehicles leaving the roadway and colliding with a hazard is given in Equation 1 and is expressed as the predicted (average) number of crashes that will occur over a year.

$$N = \frac{(E_Q G R) P_h P_i}{278} \tag{1}$$

where

N = predicted frequency of errant vehicles colliding with a hazard (number of crashes per year)

E_Q = run-off-road frequency (run-off road events/kilometre/year) for the traffic flow on the road

G = factor for grade

R = factor for curves

P_h = probability that a hazard is present

P_i = probability that errant vehicles will reach the hazard

278 = factor to convert from run-off road events per kilometre to run-off-road events per crash site

It should be noted that:

- The product (E_QGR) represents the frequency of vehicles leaving a particular section of road.
- The factor of 278 is derived from the swath width of an errant vehicle path (RTA 1996) which is taken to be 3.6 m wide (refer to Appendix G, Figure G 5). There are 278 vehicle swath widths in a kilometre (i.e. 1000/3.6).

The number of crashes estimated to occur over a year due to the presence of a hazard can then be used together with information relating to both the severity of the hazard and effectiveness of treatment options in order to evaluate options and determine appropriate action. Risk Step 1 may also be applied to a treatment option (e.g. road safety barrier) in order to assess the likely number of collisions with the option so that this can be included in the evaluation.

Risk Step R1a: Determine the traffic flow

The exposure to risk (Q) is the average annual daily traffic (AADT) for the roadway. The current traffic volume of the road can be determined from traffic survey counts. The traffic volume is then divided into the number of carriageways. For example, on a two-lane two-way road, the traffic volume would remain unchanged (i.e. it is a single carriageway), whereas for a four lane divided facility, the volume is divided by two. If a split of traffic other than 50/50 is evident, then the traffic volumes can be proportioned to each carriageway accordingly.

To allow for growth in traffic flow, the future traffic flow is calculated using Equation 2:

$$Q_n = AADT_1\left(1 + {}^{g}\!/_{100}\right)^n \tag{2}$$

here

Q_n = traffic flow on roadway in ‘n’ number of years

$AADT_1$ = annual average daily traffic on the road (both directions) in current year

g = annual percent growth in traffic

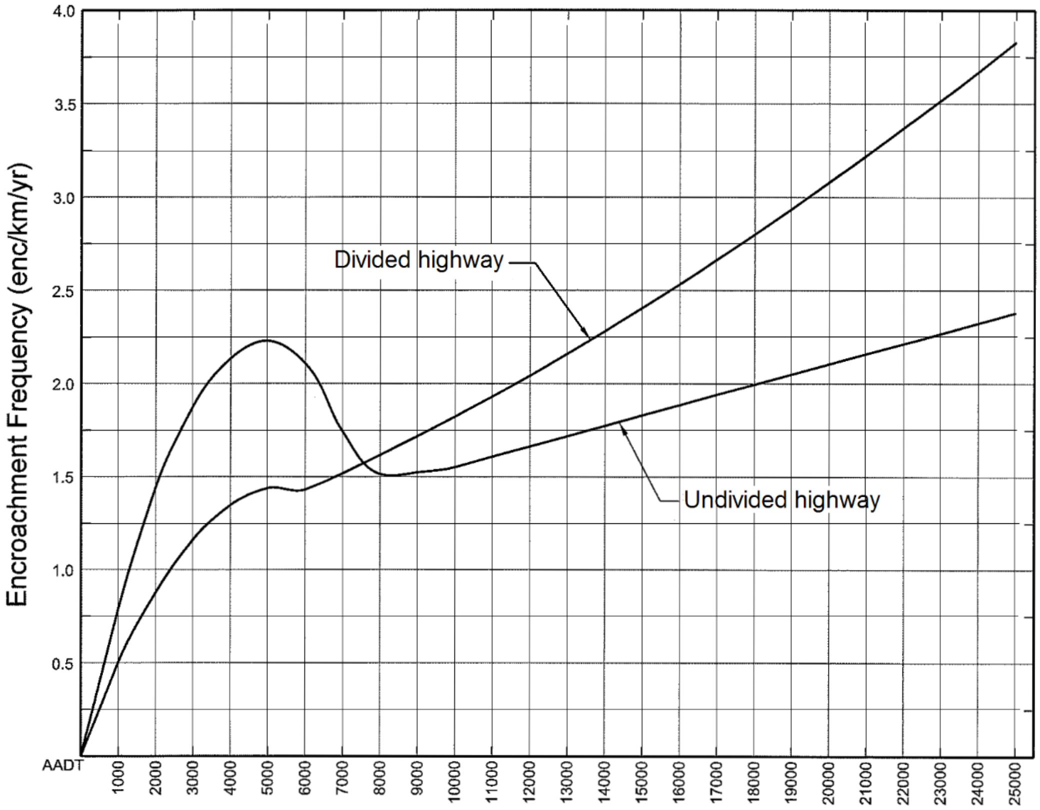
n = number of years to project into the future

Risk Step R1b: Determine the base run-off-road frequency (E)

The probability that there will be an errant vehicle is known as the encroachment frequency (E). It is measured in run-off road events/kilometre/year/VPD and together with the AADT can be used to determine the number of uncontrolled run-off-road events per kilometre per year (i.e. EQ).

Designers should consult with the relevant road authority regarding the appropriate encroachment frequency to be used for the particular situation being considered. As part of the risk assessment process each jurisdiction should determine the appropriate basis for encroachment rates to be used within the jurisdiction. For example, the Roads and Traffic Authority of New South Wales uses Figure 4.11 which is based on RSAP. Adjustments are made for the grade of the road and curvature and are determined in Steps R1c and R1d.

Figure 4.11: Run-off-road frequency curves including adjustments for controlled encroachments and under-reporting



Source: Roads and Traffic Authority of NSW.

Risk Step R1c: Determine the grade adjustment factor (G)

The presence of a downgrade can affect the encroachment frequency and therefore the run-off-road frequency is adjusted by a grade adjustment factor ‘G’ that allows for the increased likelihood of leaving the roadway when travelling downhill. The grade adjustment factor refers to the grade in the direction of travel. Grade adjustment factors are shown in Table 4.6.

Table 4.6: Grade adjustment factor for run-off-road frequency

Grade[1]	Grade adjustment factor[2] (G)
Upgrade	1.0
Flat 0%	1.0
-1% downgrade	1.0
-2% downgrade	1.0
-3% downgrade	1.25
-4% downgrade	1.5
-5% downgrade	1.75
-6% downgrade	2.0
Steeper than -6% downgrade	2.0

1 *For grades other than those shown use factor for closest gradient.*
2 *These factors are identical to those presented graphically in QDMR (2005).*

Source: RTA (2008).

Risk Step R1d: Determine the curve adjustment factor (R)

The run-off-road frequency is further adjusted by a curve adjustment factor that allows for the increased likelihood of a vehicle leaving the roadway when travelling on curves. The curve adjustment factor refers to the inside or outside of the curve in the direction of travel. Curve adjustment factors are shown in Table 4.7.

Table 4.7: Curve adjustment factor for run-off road frequency

Curve radius[1] (m)	Curve adjustment factor[2] (R)	
	Outside of curve	Inside of curve
Less than 295	4.0	2.0
300	4.0	2.0
310	3.8	1.9
320	3.7	1.9
330	3.6	1.9
340	3.4	1.8
350	3.3	1.8
360	3.2	1.8
370	3.1	1.7
380	2.9	1.7
390	2.8	1.7
400	2.7	1.6
410	2.6	1.6
420	2.4	1.6
430	2.3	1.5
440	2.2	1.5
450	2.1	1.5
460	1.9	1.4
470	1.8	1.4
480	1.7	1.4
490	1.6	1.3
500	1.4	1.3
510	1.3	1.3
520	1.2	1.2
530	1.1	1.2
540	1.0	1.2
550	1.0	1.1
560	1.0	1.1
570	1.0	1.1
580	1.0	1.0
Greater than 585	1.0	1.0

1 *For curve radii other than those shown, use factor for the closest radius.*
2 *These factors are almost identical to those presented graphically in QDMR (2005). Derived by interpolation.*

Source: RTA (2008).

Risk Step R1e: Determine the probability that a hazard is present (P_h)

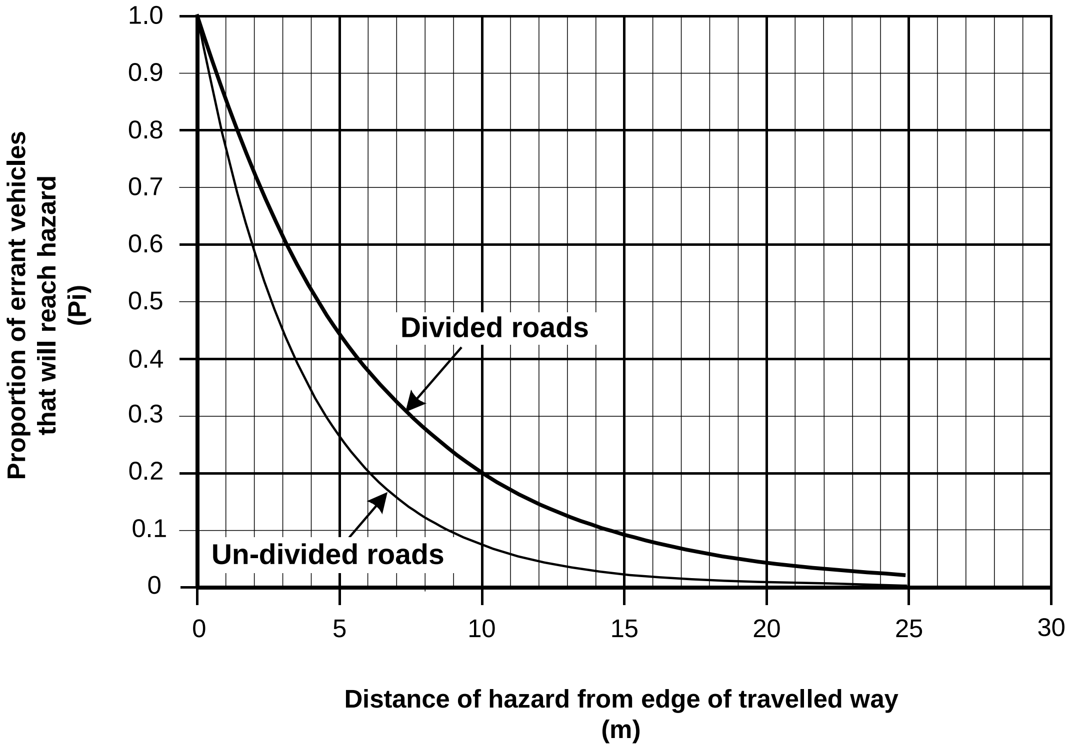
As an identified hazard is being investigated the probability that a hazard is present is a certainty or 1.0.

Risk Step R1f: Determine the probability that errant vehicles will reach the hazard (P_i)

The probability that errant vehicles will reach a hazard can be determined from a graph that relates the proportion of errant vehicles that will reach a hazard to the distance of the hazard from the edge of the travelled way.

Figure 4.12 shows relationships for divided roads and undivided roads that can be used to determine a value for P_i. The distance from the edge of the travelled way to the hazard is used to determine the proportion of errant vehicles that will be able to reach the hazard.

Figure 4.12: Proportion of errant vehicles reaching hazard



Source: RTA (2008).

Jurisdictions may prefer to use other graphs to determine P_i, for example the Queensland Department of Transport and Main Roads uses a suite of graphs where the relationships are provided for a range of operating speeds as shown in Commentary 8.

Risk Step R1g: Calculate the frequency of errant vehicle crashes

The values for the various factors from Risk Steps R1a to R1f can then be used in equation 1 to calculate the frequency of a vehicle leaving the roadway and impacting a hazard. For a section of road this process can be facilitated by using the hazard mitigation worksheet in Appendix B.

4.6.3 Risk Step R2 – Determine the Severity Index

For analytical purposes the consequences of a crash are described by severity indices (Turner and Hall 1994). This step involves an assessment of a hazard or risk reduction option in terms of the consequences of impacting a hazard by using the tables in Appendix E (from AASHTO 1996). These tables assign severity indices to various roadside hazards including road safety barriers. The severity indices are based on average crash costs when a vehicle impacts the hazard. If the situation has more than one factor, the case with the highest severity index should be selected.

It should also be noted that the severity indices shown in Appendix E are valid for occupants of light vehicles, are not suitable for motorcyclists and are probably not appropriate for trucks.

4.6.4 Risk Step R3 – Calculate Crash Cost for Hazard

Once the number of crashes that can be expected at a given location and the object's severity index are known, the expected crash cost per year can be calculated using the following relationship.

Annual crash costs per year ($) = (impacts per year) x (severity index crash cost per impact)

The impacts per year is the collision frequency calculated in Risk Step R1g and the crash costs so determined can be used as the basis for an economic analysis described in Section 4.5.2.

An example of severity index crash costs per impact is shown in Table 4.8. The table is for illustrative purposes only and combines information from two sources. Descriptions of crash outcomes in the table header (e.g. moderate injury), the percentage values in the table and the costs of the crash outcomes (on which the table is based) may all vary between jurisdictions. Designers should therefore acquire and use the latest information from the relevant jurisdiction.

Table 4.8: Example of summary table for crash cost related to severity index

Severity index (SI)	Property damage	Minor injury	Moderate injury	Hospitalisation	Fatal	Cost $
0	0	0	0	0	0	0
0.5	100	0	0	0	0	7,534
1	90.4	7.3	2.3	0	0	8,526
2	71	22	7	0	0	10,531
3	43	34	21	1	1	39,801
4	30	30	32	5	3	104,121
5	15	22	45	10	8	237,550
6	7	16	39	20	18	502,132
7	2	10	28	30	30	808,931
8	0	4	19	27	50	1,218,507
9	0	0	7	18	75	1,704,580
10	0	0	0	0	100	2,144,096

Note: The crash outcome descriptions and their unit costs are based on information published in the Queensland Department of Transport and Main Roads 'RISC Crash Costs Update'; 23 June 2008 (cost calculation date June 2007). The SI crash cost per impact shown in the right column is the sum of the cost for each crash outcome (determined by multiplying the percentage in the column by the unit cost for the relevant outcome).

4.7 Design Step D5: Rank Treatment Options and Recommend Preferred Action

Option selection refers to the process of selecting a preferred option for treatment of a particular hazard. Option selection will be required when there is more than one treatment option for a roadside hazard. Option prioritisation may be required when a number of risk reduction options have been selected for different hazards, and there is competition for limited funds. Both of these processes require a method for ranking options.

It is suggested that the options should be ranked in risk reduction order. An option at the top of the list should be considered ahead of those at the bottom.

If more than one option is available to mitigate hazards, and risk, operational and environmental factors are similar, then the options can be ranked by benefit-cost ratio.

The designer should then balance the considerations described in Section 4.4 and Section 4.5 against risk reduction and cost-benefit and select the appropriate treatment option for the hazard.

4.8 Design Step D6: Design the Roadside Treatments

This step may involve the design of a treatment for an isolated site or the preparation of a road design plan that shows a number of various treatments along a section of road that are designed to address different types of hazard. In the latter case a detailed design may be prepared for each individual treatment.

In some cases jurisdictional standard drawings will provide the necessary detail (e.g. culvert end treatments and road safety barriers) whereas the road design layout will show the location of the treatment (e.g. lateral and longitudinal location (i.e. chainage) of a barrier) as well as information not covered by the standard drawings.

Draft road designs of options should be prepared to assist in estimating costs and to facilitate approvals, together with documentation on:

- all the hazards that were considered for treatment
- the type and location of all treatment options considered
- the possibility of grouping hazards for treatment.

The lateral extent of the area of interest (i.e. clear zone or hazard corridor) should be shown on the plans as this will alert other agencies providing roadside infrastructure items (such as signage, lighting, and emergency telephones) to the areas where placing such items would present a hazard.

The final design and documentation should consolidate the design as a whole, considering:

- all hazards for which a treatment warrant has been established
- the treatment options chosen for those hazards
- the priority of the treatment options.

5. Treatment Options

5.1 General

This section expands on the summary in Section 4.4. It describes treatment options that can be used to effectively reduce risk on an existing road or in the design of a new road. As discussed in Section 3.3 the systematic approach to risk reduction in design involves:

- reduction of the inherent severity of a hazard
- prevention of an incident
- limiting damage.

It is important to understand that there may also be risks associated with treatment options and that the comparative risk of the treatment should be assessed in relation to risks associated with an untreated hazard.

5.2 Summary of Treatment Options

Research and experience has confirmed that a clear unimpeded roadside gives drivers of errant vehicles the opportunity to reduce speed, recover control of the vehicle, and thereby lessen the severity of the consequences of encroachment into the roadside. Therefore, the creation of a safer roadside may involve measures such as:

- removal of hazards
- provision of shoulders, verges and medians
- gentle slopes with firm, even surfaces and rounded batter hinge points
- traversable open drains
- extension of culverts beyond the clear zone; however, care must be taken not to cause excessive warping of the embankment slope that may affect the stability of an errant vehicle
- traversable culvert ends
- frangible supports for road furniture and road lighting
- adequate clearances to structures
- provision of underground utility services.

Where these or other measures cannot be applied or are considered insufficient and/or impracticable, it may be necessary to consider the provision of road safety barriers or crash attenuators.

5.3 Effectiveness of Treatment Options

Table 5.1 provides a subjective rating of the effectiveness of various treatments in reducing the risk associated with specific types of crashes. The table is intended to provide designers with some general guidance on the types of treatments that are likely to be most effective as a countermeasure for the specific types of crash shown in the table. The table also indicates the way in which the hazard reduction is achieved (e.g. prevention).

Table 5.1: Crash types and effectiveness of treatments

Treatment	Type of hazard reduction	Effectiveness of treatment by crash type				
		Off path, on straight	Off path, on curve	Out of control on curve	Cross-median head on	Impact with hazard
Duplicate carriageway	Reduce inherent hazard				Very high	Medium
Widen median	Reduce inherent hazard				High	
Seal shoulder	Reduce inherent hazard	High	High	High	High	
Widen or replace bridge or culvert	Reduce inherent hazard	Medium	Medium	Medium	Medium	
Improve alignment	Reduce inherent hazard	Medium	Medium		Medium	Medium
Remove roadside hazards	Prevent an incident	Very high	Very high			
Widen shoulder	Prevent an incident	Medium	Medium	Medium	Medium	
Provide overtaking lane	Prevent an incident	Medium	Medium		Medium	
Advisory speed sign	Prevent an incident		Medium	Medium		Low
Provide linemarking and guideposts	Prevent an incident	Low	Medium	Low	Medium	Low
Install road safety barriers on median	Provide protection system	Low	Low	Low	Very high	Very high
Install verge road safety barriers along length of road	Provide protection system	Medium	Medium			Very high
Resurface road	Reduce inherent hazard	Low	Medium	Medium		Medium

Note: The effectiveness of other countermeasures for non-intersection crash types is provided in the Guide to Road Safety – Part 8: Treatment of Crash Locations *(Austroads 2009a).*

Source: Based on RTA (2008).

5.4 Types of Treatments

This section discusses various treatments that may be applied to elements of road and roadside design at greenfield sites to address particular road safety issues that may emerge throughout the design process. These treatments may also be able to be applied to address safety issues relating to road and roadside designs at brownfield sites. Treatments that generally relate to brownfield sites are described in Appendix H.

5.4.1 Treatments for Trees

Trees feature prominently as impacted hazards in run-off road crashes and account for a large proportion of fatalities. Trees are a particular hazard when located within and close to curves.

Trees greater than 70 to 100 mm diameter (depending on the species) that are located within the area of interest (e.g. clear zone or hazard corridor in NSW) pose a particular hazard to motorists.

There are two areas of possible treatment for dealing with trees:

- Tree removal. This is not always an option because of environmental considerations relating to the intrinsic values of many trees and the habitat they provide. The removal of individual trees should be considered when they are in particularly hazardous locations, and maintenance patrols should ensure that naturally seeding saplings that are in hazardous locations are not allowed to mature.
- Installation of road safety barriers. Provision of a road safety barrier will depend on a number of factors relating to site conditions, crash history, economics and the environment. However, such action should only be taken where it is determined that collision with the barrier is less severe than collision with the existing hazard (i.e. trees).

Assessment of significant trees

Significant trees should be assessed in accordance with local jurisdiction guidelines before removal is proposed.

New trees

New trees should be located outside the clear zone so that they do not pose a serious roadside hazard risk.

5.4.2 Treatments for Steep Downgrades

Where a warrant has been established for treatment of a steep downgrade (refer to Section 7.3) the treatment options may include:

- a gravity safety ramp
- an arrester bed
- a dragnet
- a combination of systems.

Design of treatments needs to follow the process shown in Section 7.6.

5.4.3 Treatments for Medians

Designers should note that guidelines for the design of medians and the provision of barriers to protect drivers from severe cross-median crashes may vary between jurisdictions and therefore designers should refer to relevant road authority policy and guidelines.

Median road safety barrier selection

Median road safety barriers need to take into account the:

- impact severity at high speed which is a measure of the possible damage to vehicles and injury to occupants
- crash costs per accident including human and incident costs based on information from the relevant road authority
- width required for system hardware which has an influence on the minimum median width required
- sight distance requirements and aesthetics, i.e. the effect that the barrier will have on driver sight distance and the visual impact of the barrier
- drainage including the effects on surface water run-off
- requirement for barrier terminal treatments.

The safety benefits of safety barriers in narrow medians are described in Commentary 9.

Minimum median width

The minimum median width required to accommodate a safety barrier depends on the overall width of the barrier and the clearance required between the barrier and the edge of the traffic lane. The clearance will depend on the dynamic deflection expected under impact by the design vehicle or a nominal minimum clearance necessary for drivers to feel comfortable travelling adjacent to the barrier. Safety barriers in narrow medians are illustrated in Figure 6.6. In general it can be expected that concrete barriers will experience virtually no deflection and that steel barrier and wire rope safety barriers will deflect to varying degrees depending on the system used (e.g. post spacing, stiffness etc.). Deflection is discussed in Section 6.3.15.

Additional width will be required where a median barrier is located within a curve and the barrier will impede sight distance to objects on the road or the brake lights of vehicles preparing to stop in the median lane (e.g. due to an incident such as congestion or a crash). Some authorities may consider additional clearance is desirable because of the likelihood of vehicles shying away from a barrier.

An important consideration with respect to the clearance to median barriers, particularly the more rigid systems, is accessibility for maintenance crews undertaking repairs and the occupational health and safety issues surrounding such activities. Minimum median widths including RTA NSW requirements for wire rope safety barriers are summarised in Commentary 10.

Encroachment onto opposing carriageway

A vehicle hitting a wire rope road safety barrier (WRSB) may encroach beyond the line of the barrier, or it may cause barrier wires or posts to encroach beyond this line. On narrow medians, this may allow the vehicle or part of the barrier to encroach into the opposing carriageway and it is known that such incidents have occurred in Sweden. While experience shows that the WRSB reduces the consequences of a head-on collision by reducing the speed of the crash-causing vehicle, it is desirable to provide sufficiently wide medians to limit encroachment into an opposing carriageway.

The probability of a collision due to encroachment after impact with a WRSB in a narrow median is related to the probability of a vehicle being adjacent to the impact site during this short period of time and the design deflection being exceeded.

Issues

Issues that need to be resolved in considering median treatments include:

- incident clearance
- width of median
- provision of additional lanes in future
- sight distance
- median break influence on median width (i.e. design requirements)
- road safety barriers
- environmental impacts
- construction and maintenance
- delineation
- road user issues (e.g. pedestrians crossing roads)
- cost.

5.4.4 Treatments for Verges

Issues that need to be resolved in considering verge treatments include:

- incident clearance
- width of verge
- slopes
- provision of additional lanes in future
- sight distance
- intersections
- footways
- road safety barriers
- environmental impacts
- construction and maintenance
- delineation
- provision for drainage systems
- emergency access
- road user issues (e.g. pedestrian and cyclist facilities)
- cost.

5.4.5 Treatments for Drains

Deep, unprotected drains should not be installed at the base of cut batters. Effective redirection of vehicles requires a flat, even surface approaching the batter.

Open drains are present on the majority of rural roadsides and may exist on urban freeways. Open drains constructed close to the road may be the most efficient way of removing water but, unless they are of a suitable shape, they are a hazard for errant vehicles that leave the road.

Typical drains can be classified by whether they are designed with abrupt or gradual slope changes. Abrupt slope change designs include vee drains, drains with a rounded bottom and a width less than 2.4 m, and trapezoidal drains with bottom widths less than 1.2 m.

Vehicles leaving the roadway and encroaching into a drain face three hazard areas:

- drain front slope – if the front slope is 4:1 (14º) or steeper, the majority of vehicles entering the ditch will be unable to stop and can be expected to reach the bottom
- drain bottom – abrupt slope changes at the bottom of the drain can cause errant vehicles to roll or stop abruptly and increase the severity of the impact
- drain back slope – vehicles travelling through the ditch bottom or becoming airborne from the front slope can collide with the back slope

The *Guide to Road Design – Part 3: Geometric Design* (Austroads 2009b) provides values describing the preferred design for abrupt and gradual change slopes. Figures are provided for drain cross-sections that fall within a range of values that are considered traversable. These preferable drain designs are not considered hazardous and need not be constructed beyond the area of interest.

Drain sections that fall outside the design requirements in Austroads (2009b) (e.g. existing drains) are considered non-traversable and should therefore be:

- reshaped
- converted to a closed system (culvert or pipe)
- located beyond the area of interest
- shielded with a road safety barrier where appropriate.

If the drain bottom and slopes are free of fixed objects, non-preferred drain sections may be acceptable for projects where a better treatment is impracticable or uneconomical because of factors such as:

- a restrictive right-of-way
- rugged terrain
- resurfacing, restoration or rehabilitation projects where it is not feasible to provide a compliant shape
- low-volume, low-speed roadways.

Drains of both the abrupt and gradual slope designs can funnel a vehicle along the drain bottom, and this increases the probability of impact with any object that has high-severity attributes and is present on the bottom or side slopes of the drain. For this reason such objects should not be located within drains, apart from the potential for water flow to be adversely affected.

Back slopes typically occur when roadways are constructed by cutting the existing terrain away to develop the roadbed. If the slope between the roadway and the base of the back slope is 3:1 or flatter, and the back slope is obstacle free, then the back slope may not be a significant hazard regardless of its distance from the roadway. Back slopes that will not provide a relatively smooth redirection or that can cause vehicle snagging should begin outside the clear zone or be shielded. This usually includes rough sided rock cuts when the rough face can cause excessive vehicle snagging.

5.4.6 Treatments for Drainage Features

The ends of culverts that cross under the road or are located parallel to the road constitute hazards if they are within the area of interest (e.g. clear zone). Road design should aim to eliminate all non-essential drainage features. Where drainage features are unavoidable, they should be designed as follows:

- Drains parallel to the road (e.g. under a driveway or side road) – traversable culvert end treatments should be installed wherever a culvert exists parallel to the road and within the area of interest (Figure 5.1).
- Perpendicular to the road (headwall treatment) – Culverts that run perpendicular to the road (i.e. run under the road) should be designed to be traversable (Figure 5.2) or present a minimal obstruction to an errant vehicle if the fill batter is of a low enough slope to be driveable, or be protected with an appropriate road safety barrier if the slope is not driveable. Alternatively, the culvert can be extended to a location further from the travelled way (e.g. at the clear zone distance) where the end is less likely to be impacted by errant vehicles, although this option may not be preferred.

Figure 5.1: Example of a driveable culvert end wall for a small pipe under a driveway

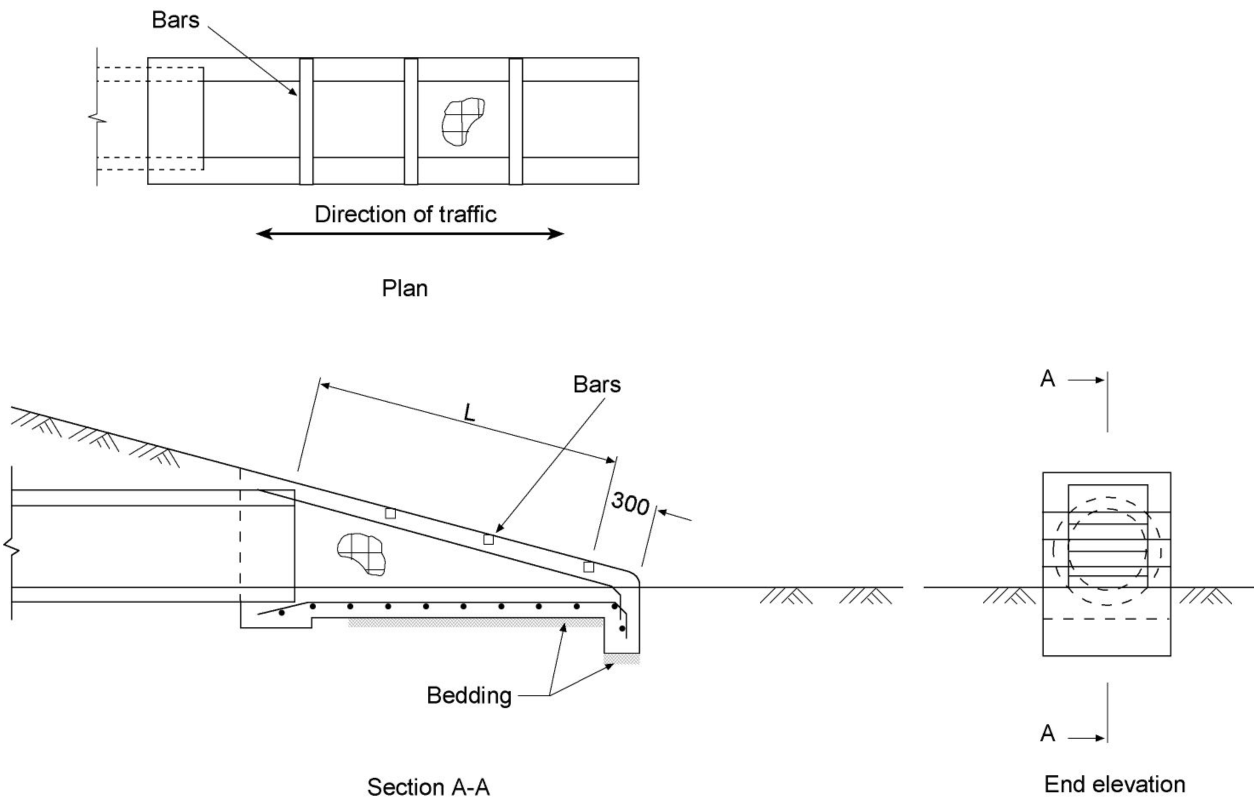


Figure 5.2: Example of a traversable culvert end treatment for a culvert under the road

Source: VicRoads.

Cross drainage of road reserves is achieved by the provision of culverts that may vary in size from a single 375 mm pipe to large multiple pipes or box culverts. The preferred open drain cross-sections described in the *Guide to Road Design – Part 3: Geometric Design* (Austroads 2009b) apply to longitudinal open drains that may convey water to transverse culverts. Transverse open drains are usually provided outside of the road formation to carry water into culverts and, unless designed correctly (i.e. with flat foreslopes and backslopes), they may also present a hazard to vehicle occupants.

Traditionally culverts have been designed with concrete headwalls and wing walls that either have resulted in a potential roadside hazard or required shielding with road safety barrier. In such cases, the options to remove or reduce the hazard caused by these obstacles are (AASHTO 2006):

- design the culvert end to be traversable
- extend the culvert to a point beyond the appropriate clear zone
- shield the culvert with a road safety barrier
- delineate the culvert if the previous options are not cost-effective or practicable.

If a front slope (embankment or drain) is traversable the preferred option is always to extend (or shorten) the culvert to intercept the roadway embankment and to match the inlet or outlet slope to the embankment slope. For small culverts no other treatment is required. A small culvert may be defined as a single pipe that has a diameter of 900 mm or less, or multiple pipes each having a diameter of 750 mm or less.

Matching culvert ends to embankment slopes is also desirable because it:

- results in a smaller obstacle for an errant vehicle
- reduces erosion problems
- simplifies mowing operations.

If a front slope is not traversable it may not be appropriate to provide a traversable end treatment, and an evaluation of alternative treatments must be undertaken (e.g. improve embankment, shield with road safety barrier).

As a significant percentage of errant traffic may travel beyond the clear zone an obstacle at this location may still be a hazard. Extending culverts to the clear zone distance without providing a traversable end is therefore not preferred, particularly on high-speed roads, as this option may create discontinuities in an otherwise traversable slope. However, if the land immediately beyond the clear zone has other hazards present that cannot be removed for practical or environmental reasons, it may be acceptable to provide a non-traversable end treatment at or beyond the clear zone distance.

Single culverts and end treatments wider than 1.0 m can be made traversable for passenger size vehicles by using bar grates. Full-scale crash tests have shown (AASHTO 2006) that cars can cross grated culvert end treatments on slopes as steep as 3:1, at speeds as low as 30 km/h or as high as 100 km/h, when steel pipes spaced at 750 mm centres are used across the opening. Although this treatment does not significantly change the hydraulic performance of the culvert, during the design process due consideration should be given to the likely accumulation of debris and level of maintenance required.

In some instances it may be appropriate not to treat the end of a culvert at all, and to simply provide adequate delineation. Provision of barriers on low-volume roads should not result in a higher risk to road traffic than not providing a barrier, given that all other things are equal. A benefit-cost analysis may show that barriers are not warranted on low-volume roads, which will occur if the benefits of installing a barrier (potential reduction in crash costs) do not outweigh the barrier installation costs.

Designers should refer to AS 5100.1 – 2004 for guidance regarding road safety barriers on bridges and designers should note that culverts are also referred to in AS 5100.1.

5.4.7 Treatments for Fill Slopes

Section 4.5 of the *Guide to Road Design – Part 3: Geometric Design* (Austroads 2009b) provides guidance on the design of batters. It is important that batters are constructed to an acceptable slope and are free of features that would prevent a driver from regaining control of an errant vehicle (i.e. drivers should be able to negotiate the slope safely). If the batter slope is severe enough to cause an errant vehicle to overturn, a road safety barrier should be considered. Design slopes for both cut and fill batters are provided in Austroads (2009b).

The concepts of recoverable, non-recoverable and critical fill batter slopes are terms that refer to the likelihood of a vehicle overturning on various slopes. After running off the road onto a recoverable batter slope, a driver will usually be able to regain control of the car and return to the road or stop safely. On a non-recoverable slope, the driver is unlikely to be able to return to the road but will be able to stop safely at the bottom of the slope. A critical slope will probably cause the vehicle to overturn.

5.4.8 Treatments for Rock Face Cuttings

Cuttings and rock faces are generally expensive to construct. Economic and environmental constraints often result in cuttings being as narrow as possible and prevent the provision of a cutting wide enough to allow a clear, flat verge beside the road. Therefore, cuttings and rock faces should be designed to provide a smooth face that will act as a rigid barrier, allowing errant vehicles to slide along and stop gradually. Uneven batter surfaces may present a hazard to vehicles that happen to run off the road (e.g. snagging and rolling). If a smooth face and approach surface cannot be provided, it may be appropriate to install a barrier to prevent vehicles colliding with an uneven rock surface.

There are no guidelines available for the acceptable roughness of rock faces. However, the degree of roughness that can be tolerated is minimal as indicated by guidelines accepted in a US Federal Highways Administration approval letter regarding the provision of vertical relief on the face of rigid barriers (FHWA 2002). The guideline (refer to Commentary 11) specifies a maximum height of 64 mm for the irregularities in the surface of the barrier above the height where wheel contact would occur.

5.4.9 Treatments for Roadway Improvements

Treatments that can be applied to the design of the road itself include the following:

- align the road to avoid the hazard
- aim to keep vehicles on the road thereby preventing collisions with roadside hazards
- provide adequate superelevation on curves
- design clear pavement marking as that is one of the most cost-effective treatments that can be applied to curves. Centrelines and edge lines are effective in directing drivers around curves and preventing run-off-road crashes
- provide audio-tactile edge lines and road markers on the shoulders to warn drivers when they stray near the edge of the travelled path
- provide advance warning signs to inform drivers of approaching curves.

Traffic calming to reduce speed

The application of traffic calming to reduce speed is generally for urban residential and collector streets where the hazards are close to the roadway and it is not economically feasible to remove, relocate or shield the poles. The use of traffic calming devices on arterial roads is generally not appropriate because arterial roads are designed for large traffic flows and to provide a high level of service and comfort for vehicle occupants, including bus passengers.

Implementing traffic calming measures to achieve lower speeds at high-risk locations can reduce the severity of the crash by decreasing the energy in the impact. Lower speed may also have some influence on reducing the frequency of crashes. Physical works are required to reduce vehicle speeds as simply reducing the speed limit is not effective, especially if the speed compliance is already low.

Traffic calming needs to be designed as an area-wide strategy because the reduction in speed may cause traffic to divert to other routes, which may increase the risk of crashes on the alternative routes.

Road re-alignment

Road re-alignment to reduce the risk of crashes is generally only feasible in conjunction with a major road upgrade program, which should include a range of measures to reduce the risk of crashes.

Road geometry changes

Relocation of merge lanes to an area with fewer roadside hazards may be possible where the merge is defined with linemarking. Road geometry changes that involve changes to pavement and kerbs should be combined with other measures to reduce the risk of crashes into roadside poles.

Delineation improvements

Delineation of the travelled path with guideposts, linemarking and signposting is an important part of keeping vehicles on the road; however, delineation cannot be relied on to prevent impacts with hazards.

5.4.10 Treatments for Watercourses, Canals and other Bodies of Water

Bodies of water can be a hazard for road users and should be considered for mitigation, particularly when they are within the clear zone but also if they exist beyond the clear zone or beyond a run-out area associated with a gating end terminal. Table 4.3 describes this type of hazard and the factors that should be considered.

When considering potential water hazards road designers should visualise the paths that errant vehicles are likely to take in reaching the water. If the water hazard is substantial and the likelihood of errant vehicles reaching the water is high, consideration should be given to the provision of shielding to prevent errant vehicle access to the likely path.

5.4.11 Treatments for Minor Roadside Hazards

Minor roadside obstacles such as fences, fire hydrants, mailboxes and other roadside hazards can pose a serious risk to an errant vehicle that may strike the object. Objects containing horizontal rails capable of spearing vehicles (such as post-and-rail fences) can be particularly hazardous. Such objects should be located outside the area of interest (clear zone or hazard corridor in NSW) or in a way that impact with the object should not result in a serious crash. Where this is not practicable, it is essential that objects located close to the road are designed to minimise risk to road users and this will often require them to be frangible.

5.4.12 Treatments for Road Furniture

As for other roadside furniture, traffic signal poles can pose a hazard for any errant vehicles. They are often necessarily located close to the travelled path at intersections, which could lead to a higher risk of impact, although some measures can be taken to minimise this risk. Such measures include not locating a traffic signal pole on the outside of a curve, setting poles as far back from the travelled path edge as practicable, minimising the number of poles and installing joint use poles wherever practicable. Provision of high skid resistance at intersections can also reduce the risk of a vehicle losing control at an intersection and skidding into traffic signal poles or other roadside hazards.

Small road signs are usually supported by small diameter and thin walled metal conduits that are frangible under vehicle impact. However, larger signs require substantial supports and should either be provided with frangible mechanisms at the base of the supports (e.g. weakened timber, slip-bases with hinge points just below the sign) or be shielded by a road safety barrier or crash attenuator. Frangible bases are often not suitable in urban areas in which case the support should be located as far as possible from the travelled way or shielded.

5.4.13 Treatments for Poles

General

The hazard presented by a roadside pole is related to both its location and type of construction as these factors contribute to the hazard the pole may pose and the consequences of an errant vehicle hitting the pole. Poles that are present in road reservations to reticulate electricity are problematic in that they are generally very expensive to remove and replace with an underground supply. However, this option should be considered in appropriate situations.

Poles are a common road furniture item used to support signs (regulatory, warning, guidance, informative), road lighting and various devices. In line with the preferred treatment for roadside hazards (i.e. removal), the practitioner’s aim should be to minimise the number of poles in the area of interest.

Appendix C of AS 1742.2 – 2009 discusses aspects of longitudinal and lateral placement, mounting height for signs, orientation, post type and selection. Signs should be erected so that sight distance is not compromised. Longitudinally, signs should be located to provide enough warning for a driver to be able to make a decision and respond as necessary. It is also important that signs are spaced far enough apart longitudinally that drivers are able to process the information before encountering another sign. If these requirements are not satisfied, drivers may react abruptly and lose control of their vehicles.

Avoid placing poles close to the roadway

Any roadway improvement that involves reconstruction of utility services should take the opportunity to avoid placement of poles close to the roadway. This proactive approach will avoid problems rather than having to rectify them in future.

Minimum lateral setback distances for signs and for road lighting poles are specified in AS 1742.2 – 2009 and AS/NZS 1158.1.3 – 1997 respectively. Where possible, poles should be located such that an errant vehicle is unlikely to hit them.

Pole removal

On tangents to curves where there is a crash history the removal of a pole may lead to crashes migrating to the next available pole. When considering removal of a pole with a crash history it is important to understand why vehicles are leaving the road and take action to keep vehicles on the road.

Undergrounding cables

Relocation of utility services to underground ducts and removal of the poles is the most effective option for the treatment of hazardous poles.

Rationalisation of pole functions

It may be possible to rationalise the number of poles along a road corridor by combining separate functions and services onto common poles. For example, traffic signals, road lighting and large signage may be supported by the same poles. Power cables, telecommunication services and spotlights can share common poles.

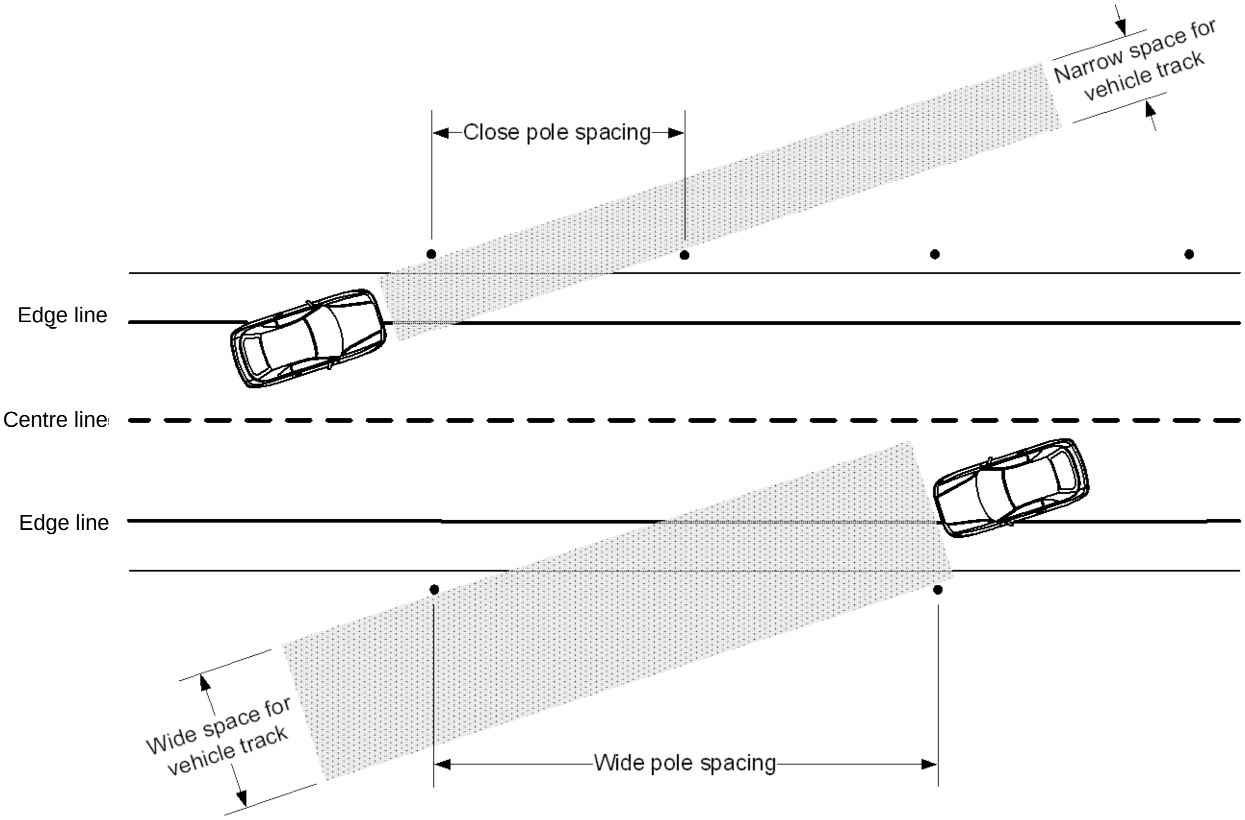
It may be possible to place all poles on the side of the road that has the better safety performance or least risk. This may involve changing the poles from side to side as the crash risk changes along a curved route.

Reducing pole numbers by increasing spacing

Increased pole spacing provides areas for errant vehicles to pass between poles as shown in Figure 5.3. The effective gaps for vehicles to pass through are dependent on the width of the vehicle and the exit angles.

If increased pole spacing is used to reduce the roadside risk then designers should check that the poles being removed to increase pole spacing are those that have been involved in crashes or have the higher risk. It would be counterproductive to remove poles which have not been a hazard but leave the high-risk poles in place.

Figure 5.3: Pole spacing



Source: RTA (2008).

Relocation

Pole relocation needs to target areas where the run-off-road crashes are likely, for example on the approach to curves, the outside of curves, near lane merges, lane terminations, adjacent to exits from roundabouts and intersections. Research (Zegeer & Cynecki 1984; Zegeer & Parker 1984) has confirmed the belief that the number of crashes decreases as poles are moved further from the roadway.

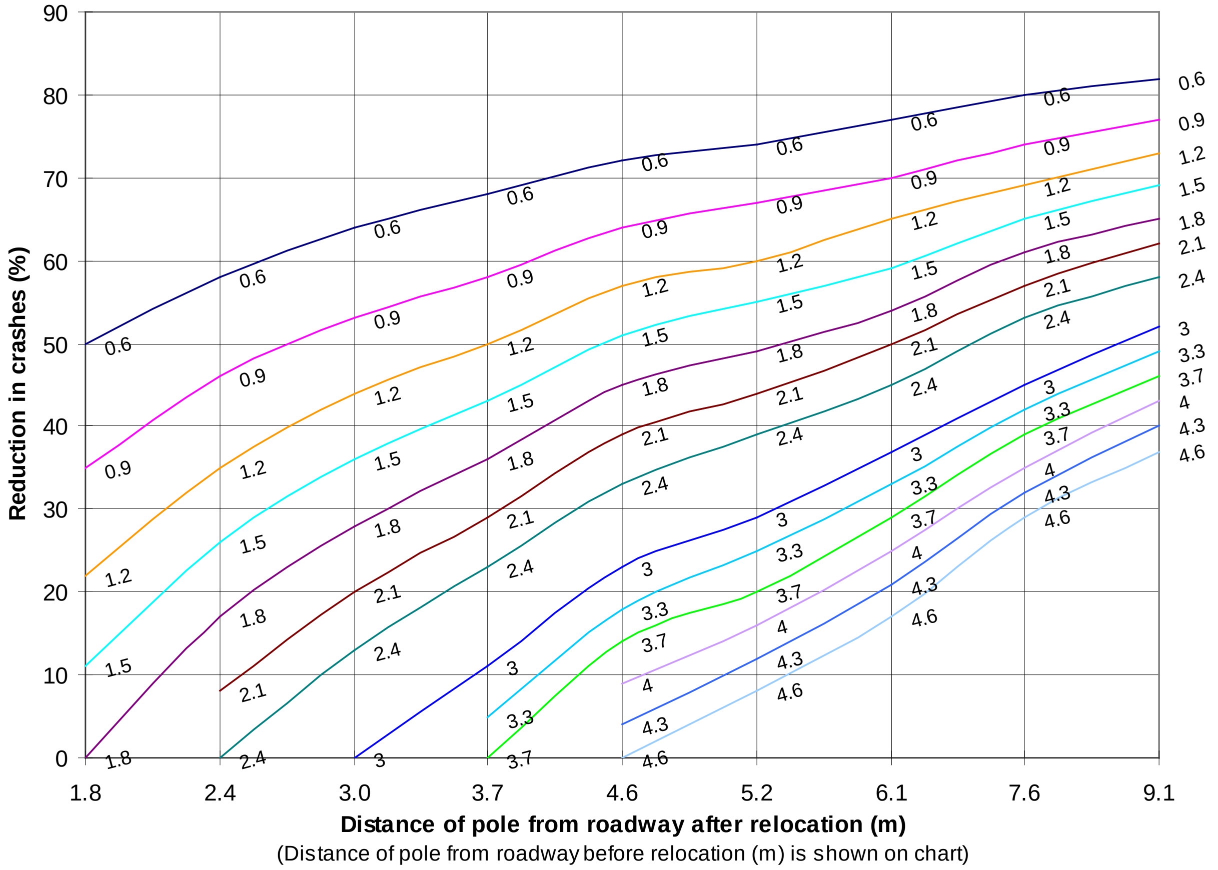
The expected percentage reduction in pole crashes with increasing distance from the roadway is shown in Table 5.2. The data is shown graphically in Figure 5.4.

Table 5.2: Percentage reduction in pole crashes with increasing distance from the roadway

Distance from roadway before relocation (m)	Distance from roadway after relocation (m)								
	1.8	**2.4**	**3.0**	**3.7**	**4.6**	**5.2**	**6.1**	**7.6**	**9.1**
0.6	50	58	64	68	72	74	77	80	82
0.9	35	46	53	58	64	67	70	74	77
1.2	22	35	44	50	57	60	65	69	73
1.5	11	26	36	43	51	55	59	65	69
1.8	0	17	28	36	45	49	54	61	65
2.1		8	20	29	39	44	50	57	62
2.4		0	13	23	33	39	45	53	58
3.0			0	11	23	29	37	45	52
3.3				5	18	25	33	42	49
3.7				0	14	20	29	39	46
4.0					9	16	25	35	43
4.3					4	12	21	32	40
4.6					0	8	17	29	37

Source: RTA (2008).

Figure 5.4: Percentage reductions in pole crashes with increasing distance from the roadway



Source: RTA (2008).

Reduce impact severity

The use of frangible poles may be effective in reducing the severity of pole-related crashes, if pole removal or relocation is not feasible. These types of poles are designed to collapse or break away on impact and thereby reduce the severity of injuries to the occupants of an impacting vehicle, compared to those that could occur if the pole was rigid.

Frangible poles

Rigid poles do not deform to a great extent, but are designed so that they remain upright after an impact. Alternatively, frangible poles are designed to deform upon vehicle impact and are usually used for road lighting poles as the lighting needs to be close to the road. Types of frangible poles include:

- Slip-base poles that break away at the base upon impact, allowing the vehicle to pass beneath the pole in order to minimise or avoid injury to vehicle occupants.
- Impact absorbing poles that collapse over the colliding vehicle and are designed to bring the vehicle to a controlled stop at the base of the pole. These deformable poles are designed to remain in the ground after being hit.

The following issues need to be considered when specifying frangible poles to reduce impact severity:

- removing or relocating the pole should be considered before specifying frangible poles
- the area behind the pole should be free of other hazards and in the case of break away poles a run-out area may be required
- there should be limited pedestrian activity in the vicinity of the pole
- the damaged pole and any elements that detach under impact should not pose a risk to other road users

Impact absorbing poles should be favoured over slip-base poles where there is closely abutting development, pedestrian and parking activity and a low traffic speed environment.

Signposts should be designed to be frangible in the event of impact by an errant vehicle (i.e. posts that are designed to fracture, break away, give way or bend), such that the damage to a colliding vehicle and risk of injury to vehicle occupants upon impact is minimised. Small signs are usually supported by posts that deform in a way that causes minimum damage to cars, whereas larger posts and supports (for larger signs) may be provided with mechanisms that are designed to yield in a controlled manner upon impact.

Aspects to be considered in the selection of pole type and setback from the roadway include:

- surrounding land use
- pedestrian activity
- speed limit
- whether the road is kerbed or un-kerbed
- location (mid-block or at an intersection)
- whether the pole is to be located behind a road safety barrier
- maintenance.

This may involve locating them at the property line (urban and rural) or in an easement (rural).

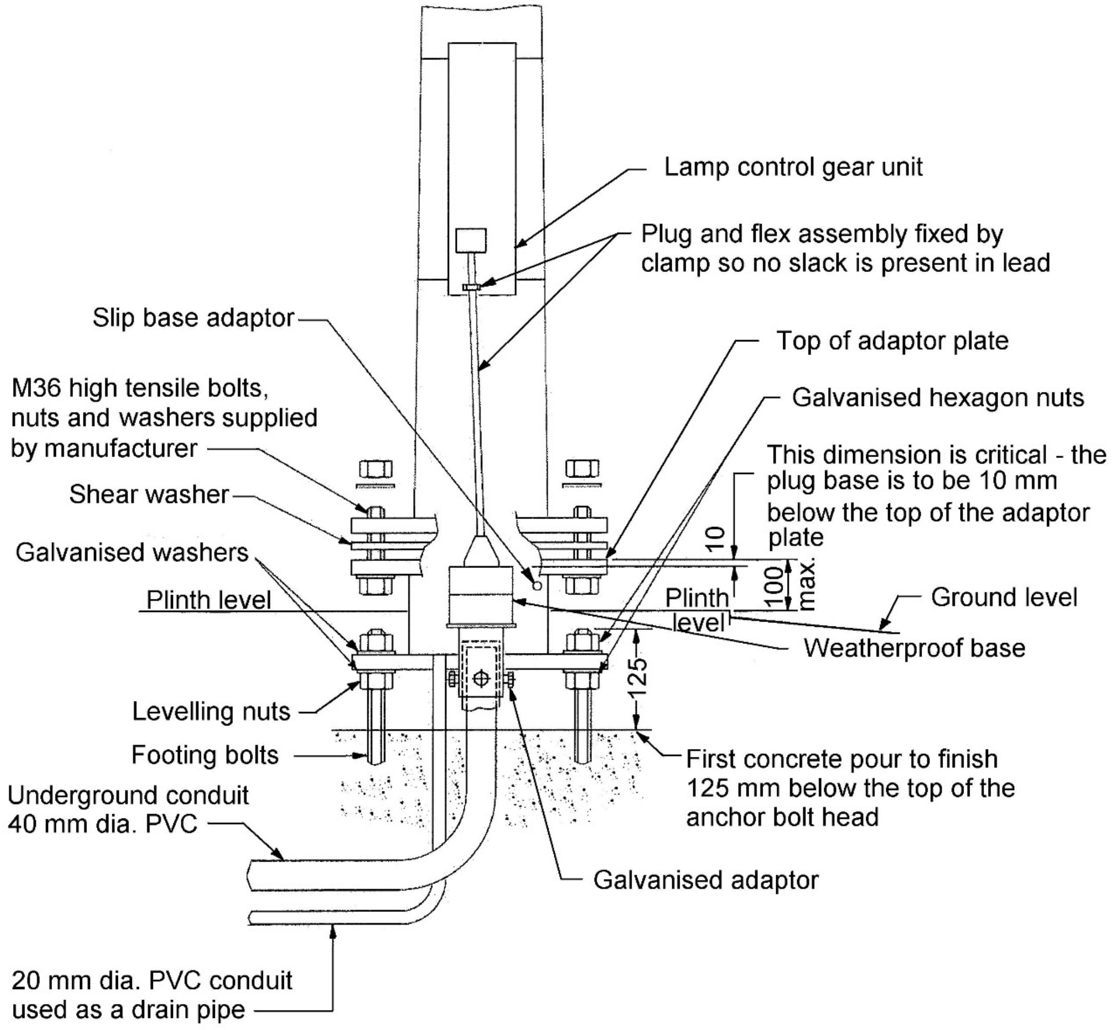
Slip-base poles

Slip-base poles consist of a standard pole stem, mounted on two base plates that are clamped together with bolts that release on impact thus allowing the pole stem to break away from its foundation. An example is shown in Figure 5.5. A disadvantage with slip-base poles is that the dislodged pole may create a secondary incident by falling on bystanders or adjacent vehicles.

The decision to use slip-base poles will depend on the space available and the resultant likelihood that a falling pole would cause injury to other users of the road or roadside area. For example, a slip-base pole will usually be inappropriate where pedestrian or cyclist traffic is common because a falling pole may pose an unacceptable risk to those road users.

Lack of maintenance is a significant problem with slip-base poles. They should be checked regularly to ensure they are free to slide and the bolt tension is correct. Wind vibration can cause poles to move the assembly and jam the bolts.

Figure 5.5: An example of a slip-base pole mechanism



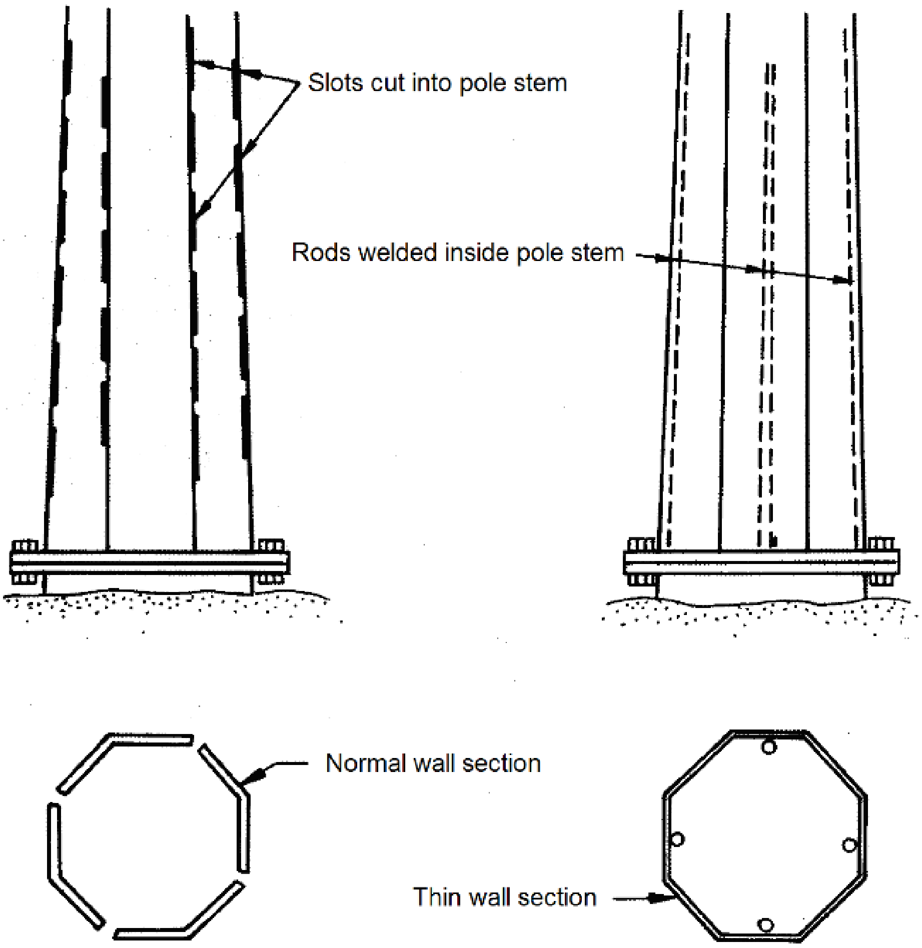
Source: Based on RTA (2008).

Impact absorbing poles

Impact absorbing poles remain attached to the base structure and absorb impact energy by progressively deforming and entrapping the impacting vehicle. The deformation of the pole is controlled by a designed weakening of the pole stem. Figure 5.6 illustrates that concept of an impact absorbing pole.

Impact absorbing poles have less maintenance issues than slip-base poles.

Figure 5.6: Examples of impact absorbing poles



Source: Austroads (2004).

5.4.14 Road Safety Barriers

The purpose of road safety barrier systems is to shield vehicles from striking a hazard. However, it is important to note that impacting a road safety barrier is a hazard for vehicle occupants although usually less severe than impacting a rigid object in the road reserve (e.g. pole or tree). Road safety barrier systems may increase the likelihood of vehicle impacts because they are longer than the point hazards they shield and are closer to the traffic.

Installation of a road safety barrier in front of a hazard requires space for dynamic deflection, vehicle roll, system width, sight distance, sufficient length for terminals, and a run-out area for terminals. On constrained road reserves it may be necessary to consider other options (such as hazard relocation) because there is insufficient space to install a road safety barrier.

Road safety barriers should be designed in accordance with Section 6.

5.4.15 Road Safety Barriers on Corners of Intersections

When a W-beam road safety barrier system is installed around a small radius curve the posts should be weakened as described and illustrated in Figure L 1 and Figure L 2 in Appendix I. These treatments should be provided with a flat area graded at 10:1 or less and free of fixed hazards as shown in the figures. If these criteria cannot be met then a non-weakened barrier is to be installed.

The use of the weakened W-beam is more critical at higher-speed locations (i.e. > 80 km/h).

5.4.16 Treatments at Level Crossings

Short lengths of road safety barriers around level crossing equipment may be ineffective because of the short length, and may present a greater hazard to road users than the equipment behind the barrier. Alternatives are to install level crossing equipment as far from the edge of the travelled way as possible and define the approaches with enhanced delineation.

5.4.17 Weather Warning Systems

A range of conditions related to weather can have an adverse affect on vehicles staying on the road through their impact on drivers (e.g. reduced visibility, strong crosswind) or the road surface. Common conditions include:

- heavy rain
- ice and/or snow
- fog
- water on road
- strong winds.

Weather warning systems may be used in locations where the adverse effects of weather are known to increase the risk of road crashes. This may be as simple as permanent signs, but more complex systems are also possible. For example, an ice warning system can consist of warning lights and signs that are activated by inputs from temperature and humidity sensors. Similarly, a fog warning system could activate advance warning signs and lights in response to inputs from a visibility detection device.

If a system is proposed, several years of crash data should be examined to determine that the weather conditions did influence crashes at the site.

An example of a weather warning system is shown in Figure 5.7.

Figure 5.7: Example of a weather warning system

Source: RTA NSW.

6. Road Safety Barriers

6.1 Introduction

6.1.1 General

A possible outcome of a roadside safety assessment (using the hazard mitigation process in Figure 4.1) during the design of a new road or re-design of an existing road, is that roadside hazards will need to be shielded by a road safety barrier system.

This section provides a general description of the types of road safety barriers, crash cushions and other devices available and discusses factors that should be considered in selecting an appropriate type of barrier and designing suitable layouts for barriers. It also describes the process and considerations involved in designing barriers. However, designers should read this guide in conjunction with AS/NZS 3845 – 1999 – *Road Safety Barrier Systems* which covers standards relating to the use of barriers in Australia and New Zealand.

Road safety barriers are broadly described as flexible, semi-rigid or rigid. Wire rope barriers used in Australia and New Zealand are tensioned.

A barrier should only be installed when the consequences of vehicle impact with the barrier are likely to be less severe than the consequences of impact with the feature being shielded. Generally, the likelihood of striking a barrier is greater than striking the hazard (e.g. a tree some distance further from the road). However, the severity of an impact with the barrier is usually much less than that associated with striking the hazard.

For hazards adjacent to existing roads, alternative options should be considered before a decision is taken to install a barrier. These may include improvements to the road (e.g. alignment, cross-section, pavement surface, delineation) and/or the removal or treatment of hazards. Options for the removal, treatment or shielding of roadside hazards should be considered during the planning and design phases of projects.

Only road safety barriers and end treatments approved by the relevant state or national road authority should be used in that jurisdiction. The road safety barriers and end treatments covered in this guide generally comply with AS/NZS 3845 – 1999. However, other devices may be used with the approval of the relevant authority following a product acceptance process that includes testing. When using proprietary products it is important that reference is made to the relevant manufacturer's manuals and specifications.

In New Zealand, all state highway roadside safety barrier systems must comply with NZTA Specification M/23 (Nz Transport Agency 2009). The minimum performance level for state highway safety barriers is TL – 3 and evidence of compliance with this, or a higher specified NCHRP 350 (Ross et al. 1993) test level, must be provided when requested.

6.1.2 General Requirements for Road Safety Barrier Systems

Barrier systems should be accepted or approved for use by the relevant national or state road authority. It is generally required that the use of road safety barrier systems should be:

- Supported by technical literature and assembly instructions that clearly demonstrate the essential mode of operation and prominently show the test level achieved in crash testing carried out in accordance with AS/NZS 3845 – 1999.
- Selected and located in accordance with a recognised design procedure that is professionally applied. The procedure is to take account of risk management techniques that address the community of road users and neighbours that may be affected by the installation. The hazard mitigation and design procedures in this guide meet these requirements.

- Erected in accordance with manufacturers' instructions.
- Maintained in a manner that reflects specified requirements.
- Returned into service only after professional evaluation and execution of repairs.
- Fitted with end treatments and interface devices that are appropriate.

6.2 Factors Considered in Barrier Selection

This section provides general guidance for initial selection of longitudinal barrier systems, remembering that the best solution is one that provides the required degree of shielding at the lowest whole of life cost (AASHTO 2006). It should also be noted that end treatments are covered in Section 6.3.22 and Appendix J.

A pre-requisite to the selection of a barrier is a risk assessment and an evaluation of the economic viability of other possible measures compared to the provision of barriers. The various factors that should be considered in selection of the type of barrier to be adopted are summarised in Table 6.1.

Table 6.1: Selection criteria for roadside barriers

Criteria	Comments
1. Performance capability	Barrier must possess sufficient structural integrity to contain and redirect the design vehicle.
2. Deflection	Expected deflection of a barrier should not exceed available room to deflect.
3. Site conditions	Slope approaching the barrier and distance from the carriageway may preclude use of some barrier types.
4. Compatibility	Barrier must be compatible with the planned end anchor and be capable of having suitable transition segments (i.e. of adequate stiffness) installed to join to other barrier systems (such as bridge railing).
5. Cost	The cost of barrier systems vary but high-performance barriers designed to contain and redirect heavy vehicles generally cost significantly more.
6. Maintenance	The cost of repair has to be assessed independently.
a. Routine	Few systems require a significant amount of routine maintenance.
b. Collision	Generally, flexible systems require significant repair after a collision, semi-rigid systems have fewer repair requirements and rigid systems or high performance railings require an even smaller amount of repair, sometimes nil.
c. Materials storage	The fewer different systems used, the fewer inventory items and the less storage space required.
d. Simplicity	Simpler designs, besides costing less, are more likely to be constructed and repaired properly by field personnel.
7. Aesthetics	Occasionally, barrier aesthetics is an important consideration in its selection.
8. Field experience	The performance and maintenance requirements of existing systems should be monitored to identify problems, especially those which could be lessened or eliminated by using a different barrier type.

Source: AASHTO (2006).

In some situations environmental impact may also be a factor in the choice of barrier. For example, a section of a road may be of high value to the tourism industry and the visual amenity of the road and roadside may require the choice of a barrier that is constructed of alternate materials, or that a safety barrier is not provided at all. Sight lines through the barrier to allow glimpses of scenic vistas, or for operational purposes, are an acceptable selection criterion.

The appearance of a road safety barrier system may also be an important issue at some sites where compatibility with other architectural or geological features is essential.

The first two factors from Table 6.1 are discussed in more detail in Section 6.3 as part of the design process. However, the following information is provided for the other factors that may need to be considered.

6.2.1 Site Conditions

The key site factors that need to be assessed include road geometry, offset distances and cross slopes.

Road geometry:

- Some systems, such as wire rope barriers, have restrictions in regard to their use where the horizontal and vertical alignment standards are less than that specified by the manufacturer.

Offset:

- The objective is to minimise both the probability of a barrier being impacted by an errant vehicle and the severity of any collision with the barrier. In general, provided that the roadside would enable an errant vehicle to recover, it is desirable that road safety barriers be located as far as possible from the edge of the traffic lane as site conditions permit. This will maximise the chance of the driver being able to regain control of the vehicle and also minimise the length of barrier required and the hazard it presents. However, a greater offset from the edge of the lane can result in larger impact angles, higher impact severity and a higher probability of the barrier being penetrated. This aspect also requires consideration.
- It is essential that the most appropriate barrier is selected to suit the particular site. Rigid barriers should generally be located between 1.0 m and 3.0 m (and no more than 4.0 m) from the edge of the through lane as the angle of impact for errant vehicles may increase with offset. At increasing impact angles the rigid barrier profile becomes ineffective and injury severity increases.
- When located adjacent to horizontal curves, road safety barriers may need to be offset further from the edge of the traffic lane so that they do not impede horizontal sight distance (refer to the *Guide to Road Design – Part 3: Geometric Design* (Austroads 2009b).
- Sufficient width should be provided between the road safety barrier and the traffic lane to enable stationary vehicles to park clear of through traffic. Also, the full width between the pavement and a concrete barrier should be paved to ensure optimum barrier performance, and consideration should be given to sealing the shoulder.
- When road safety barriers are used to shield embankments, consideration needs to be given to the provision of adequate ground support as over time softening of the verge may occur. For example, where the restraining mechanism is supported on posts, a clearance of not less than 500 to 600 mm from the rear of the post to the top hinge point of a fill embankment should be provided, although this may vary due to soil conditions, batter slope, post depth, and other factors. In situations where post restraint is of concern, deeper post embedment, closer post spacing or the use of soil plates may be considered. A soil plate is attached to the bottom end of the post to increase the area of post available to resist moment forces arising from vehicle impact. Reference should also be made to the manufacturer’s specifications.

Cross slopes:

- Irrespective of the type of barrier being used it is preferable that the approach slope is essentially flat because road safety barriers perform best when they are impacted by vehicles with their centre of gravity at or near the normal position.
- In general, semi-rigid and flexible barriers should not be used where the slope in front of the barrier is steeper than 10:1. An exception is where it is necessary to provide a drain in a median and also to locate a barrier within the median in which case a 6:1 slope may be acceptable, but only if it is not practicable to achieve 10:1.

Compatibility

As a general practice road authorities use a limited number of different, proven road safety barrier systems on new construction and reconstruction. This practice has advantages in that maintenance personnel need to be familiar with only a few systems and stocks of replacement parts are more easily managed. Non-standard or special barrier designs need only be considered when site characteristics or performance requirements cannot be met with standard systems.

Cost

The selection of a barrier should consider the life cycle cost of the systems and their safety performance, including injury and property damage costs, and maintenance costs. Initial capital cost of the barrier is only one component of economic evaluation; however, this is not to say that the initial cost of the system is not an important budgetary and project management consideration.

The choice of a terminal treatment may also be a significant factor with respect to the cost of the system.

Maintenance

A barrier can perform as intended only if it is properly installed and maintained. Maintenance factors that need to be considered are:

- routine maintenance of the barrier itself
- impact repair
- effect of the barrier on adjacent road and roadside maintenance (pavement overlays, etc.)
- material and component storage requirements.

Aesthetics

Aesthetics are not normally an over-riding factor in the choice of barrier. However, greater importance is now being placed on the aesthetics of road safety barriers, especially in recreational and tourist areas. Section 6.6 provides some information on aesthetic road safety barriers. It may also be preferred for aesthetic reasons that a particular type of barrier is used consistently along a road or section of road.

Field experience

There is no substitute for documented evidence of a barrier's performance in-service on the road. This information provides feedback to designers and construction personnel on the performance of various types of barrier in various situations. It is particularly important that road authorities learn from both observing the results of impacts with barriers and from examining crash reports.

Environmental impact

Apart from the aesthetic appeal of the barrier, other environmental factors that may require consideration are that:

- barriers that have a larger frontage area may contribute to a build-up of drifting snow or sand, thereby affecting operation of the road and potentially the effectiveness of the barrier
- the use of certain preservatives in some wooden barriers or barriers that have wooden components may be an issue
- some types of steel railing may deteriorate rapidly in highly corrosive environments
- solid barriers may block tourists’ views of scenic panoramas, or a driver’s sight distance
- fauna migration patterns.

Limitations on the use of barrier types

There are some key factors (Table 6.2) that must be considered in the selection of a barrier type to ensure that it is suitable for the particular circumstances. However, it is important that designers also consult the relevant national or state jurisdictional guidelines in choosing a barrier. It should be noted that some national and state road authorities may have a product acceptance process for barriers proposed for use on their roads.

Table 6.2: Key considerations in barrier selection

Type of barrier	Consideration
Flexible	Ground slope • The maximum lateral slope on which wire rope road safety barrier (WRSB) should be installed is typically 10:1. • If it is proposed to install WRSB on steeper slopes, all relevant factors must be considered including confirmation from the distributor/manufacturer that the proposal is acceptable. It should be noted that flexible barriers have the advantage of smaller exit angles compared to rigid and semi-rigid barriers. Recent developments have seen considerably larger post spacing proposed for flexible barriers (i.e. > 4 m) which may be advantageous in some situations. However, this is only one of many factors to be considered. Horizontal curves • Careful consideration is required where the horizontal radius is less than 200 m because the required rope tension and height may not be maintained during or after an impact. • Designers should consult with WRSB manufacturers where it is proposed to install it on curves less than 600 m radius. Vertical curves • Road designers should be aware that there may be limitations regarding the use of a flexible barrier on vertical crest and sag curves. For example, on sharp sag curves the tension in the ropes may cause the posts at the bottom of the dip to lift out of their sockets, especially in cold weather. As specific requirements may apply to particular products, designers should refer to product information and jurisdictional guidelines. • A sag curve, combined with the possibility of the suspension of an errant vehicle being compressed at the bottom of vertical sag curve, may lead to an occurrence where the vehicle body passes under the ropes, instead of being caught on them. The ropes may then encroach into the turret of the vehicle causing injury to the occupants. Transitions • WRSB systems should not be installed so that they connect directly to any other barriers or bridge parapets. The deflection (refer to Table 6.7) inherent in the design cannot ensure that vehicles colliding in the transition area between the rope barrier system and another system will be redirected safely. • WRSB may be installed in close proximity to rigid or semi-rigid barriers provided that there is sufficient distance between the barriers to accommodate the dynamic deflection. Barrier length • The minimum length of WRSB at full height should comply with the manufacturer's specifications (e.g. not less than 24 m). This length does not include the transition from full height to the end anchors. • In assessing the maximum length of WRSB between end anchorages and the spacing of intermediate anchorages, the designer should consider the effect of barrier length on maximum deflections and the risk of long lengths of barrier being made ineffective due to an impact at the barrier terminal. The manufacturer and road authority should be consulted when determining anchorage spacing.
Semi-rigid	Horizontal curves • W-beam and Thrie-beam barriers perform well on the outside of curves, even those of relatively small radius, as the concave shape (in plan view) supports the development of tension in the rail. • The convex (plan view) when used on the inside of small radius curves can mitigate against the development of tension in the rail. However, this is usually only a problem for very small radii such as those on the corners of intersections (refer to Section 5.4.15) for which appropriate designs have been developed. Barrier length • As a general guide, 30 m can be taken as the minimum length of semi-rigid barrier that should be installed.

Type of barrier	Consideration
	Kerbs • Where a kerb exists at the edge of the road, semi-rigid barrier must either be placed within 200 mm of the face of the kerb or a distance behind it to ensure that impacting vehicles do not vault over the barrier (Commentary 12).
Rigid	Horizontal curves • Rigid barrier should generally not be used in situations where it is likely to result in impacts occurring at high angles as this could subject vehicle occupants to high severity crashes. • Where practicable, the use of rigid barriers on the outside of small radius horizontal curves should be avoided for similar reasons. However, it is acknowledged that this is not possible in all situations, particularly adjacent to ‘loop' ramps at urban freeway interchanges (although impact speed should be relatively low in this situation). Length • The minimum length requirement for a rigid barrier in order to provide adequate contact length is 20 m – 30 m. Drainage • Provision of outlets should be provided to discharge stormwater from the road pavement.

6.3 Road Safety Barrier Design Process

6.3.1 Outline of Process

Once a road safety barrier has been clearly established as the preferred treatment using the hazard mitigation process in Figure 4.1 a road safety barrier design can be undertaken in accordance with Figure 6.1. In designing a safety barrier system it is important that all system components meet the required test level over the entire length of the barrier.

Figure 6.1 shows that the road safety barrier design process includes:

1. Collection of information about the site such as geometry, speed zoning, AADT etc.
2. A clear understanding of the objectives of the proposed road safety barrier.
3. Choice of a trial lateral location for the barrier.
4. Confirmation that the clearance between the barrier and the hazard can accommodate the required working width for the chosen barrier type.
5. The choice of a type of barrier for further consideration.
6. Where necessary, choice of an alternative barrier type and a repeat of points 3 and 4.
7. Development of detailed aspects of the barrier design such as the:
    a. transverse location of the barrier and any site modifications necessary to ensure that impact height criteria are met
    b. points of need and length of need
    c. treatment of leading and trailing terminals
    d. details of interfaces where different types of road safety barrier systems meet (such as a road safety barrier meeting a bridge barrier).

At all sites where hazards have been identified, it is important to realise that drivers expect a consistency of treatment (in accordance with current design practice), along sections of road that have similar features.

Steps B1 to B3 in Figure 6.1 are discussed in Sections 6.3.2 to 6.3.4 respectively and Steps B4 to B16 are discussed in Sections 6.3.12 to 6.3.24 respectively.

6.3.2 Step B1 – Collect Site Information

The information that may be required to commence the process includes:

- general site details
- the size and position of identified hazards requiring protection (length, width and offset from the carriageway) and their risk levels
- detailed topographic information such as embankment details, lateral widths, crossfalls, topography at the leading end of the road safety barrier system and any restrictions on the use of gating terminals
- features of the site which could pose difficulties such as public utilities, access to property, drainage installations, site geology, maintenance access requirements to road furniture and the like etc.
- locations where restrictions to sight distance could be critical, such as curves and intersections
- the location, type and condition of any existing barriers
- traffic volume and mix, including of pedestrians, bicycles, motorcycles, heavy vehicles
- design vehicle (e.g. mass and principal dimensions)
- intended design speed for the road
- impact speed and impact angle
- the nature of the ground in front of the road safety barrier system, sufficient to allow the likely approach elevation of an errant vehicle to be established
- provisions for access (e.g. vehicles, pedestrians, fauna crossings)
- period of time the road safety barrier system will be required to operate
- existing delineation
- operational temperature range
- flooding.

6.3.3 Step B2 – Determine the Objectives of the Safety Barrier

From knowledge of the site the designer should determine the objectives of the proposed barrier, by considering who (persons-at-risk) or what vulnerable site is to be protected or shielded.

In the majority of cases the primary persons-at-risk are the occupants of errant vehicles. The vast majority of barrier installations are provided for the purpose of re-directing errant vehicles away from hazards thereby reducing the risk of severe consequences.

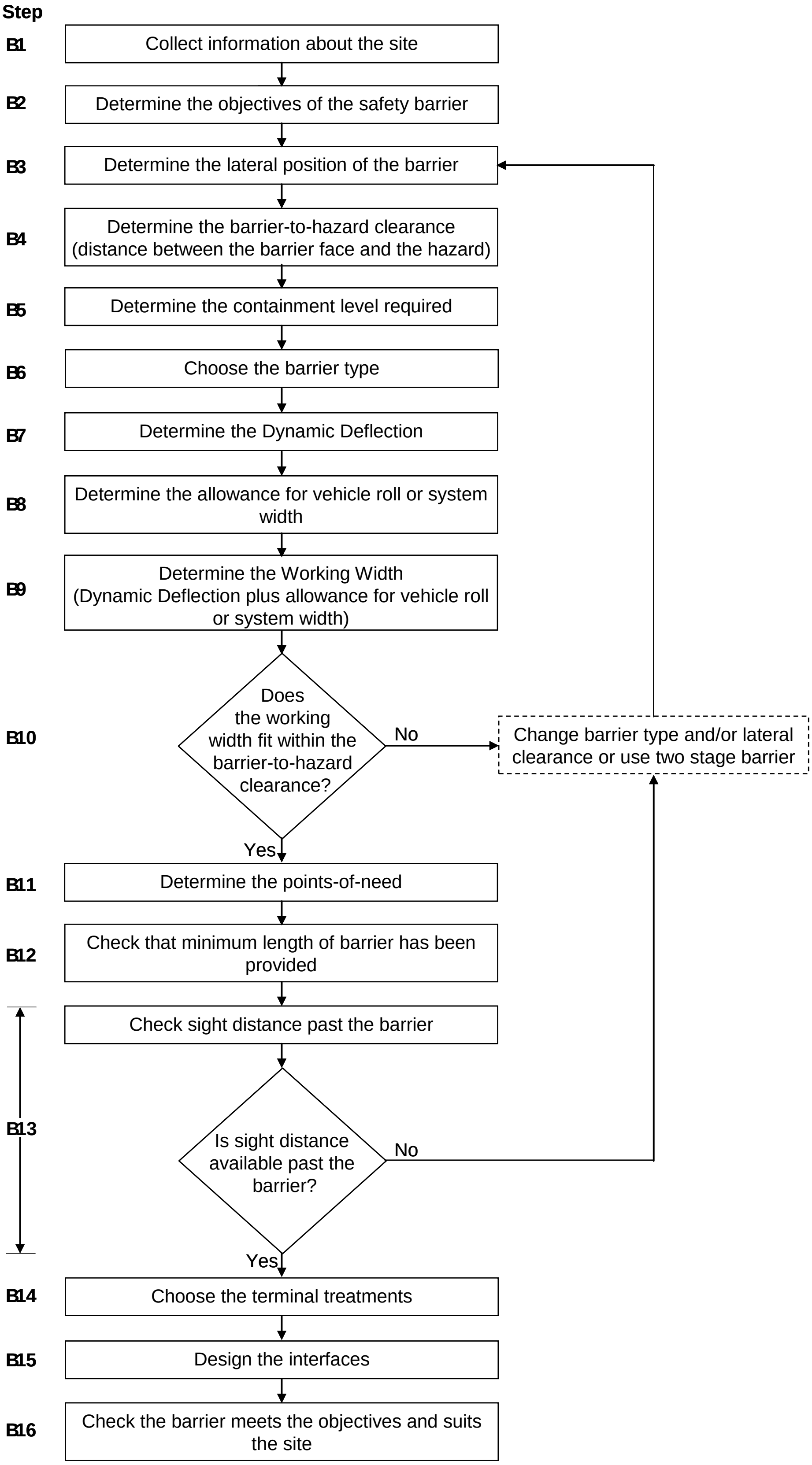
In some cases, however, the primary persons-at-risk might be the occupants of a property (e.g. children in a child care centre) in a vulnerable location such as at a curve where there is a history of run-off-road crashes or at the bottom of an embankment. In this case the occupants of the errant vehicle are the secondary persons-at-risk.

In setting the objectives of a proposed road safety barrier system designers should consider the possible crash events at a site and identify the range of possible outcomes for impacts by all types of road users. Traditionally, most road safety barrier systems have been tested with typical passenger cars striking the device at relatively small angles of impact. However, road safety barrier systems may have reduced performance if impacted by:

- cars at larger angles of impact and at speeds higher than barrier test speeds
- heavier vehicles
- bicycles or motorcycles.

Similarly, on low-volume and low-speed roads, a road safety barrier system that is less expensive than a road safety barrier system designed to cope with the higher loadings may be appropriate.

Figure 6.1: Road safety barrier design process



Source: RTA (2008).

6.3.4 Step B3 – Determine the Lateral Position of the Barrier

Factors considered in lateral location

Barriers are a roadside object that can be hazardous to errant vehicles and the lateral location of the barrier can affect the roadside safety outcome. Designers should understand that a barrier located:

- relatively close to the travel lane has an advantage in that vehicles will impact it at a low angle and hence the impact will be less severe
- a greater distance from the travel lane is likely to result in less impacts but those that do occur will be at a higher angle and hence result in a more severe impact
- too close to the travel lane is likely to be impacted more frequently, cause more damage to vehicles and the barrier and hence result in higher property damage costs for road users and higher maintenance costs for road authorities.

In addition to operational considerations, a road safety barrier and its footings should not:

- interfere with any utilities, drainage conduits or structures
- impair access of personnel or machinery to any utilities, drainage conduits or installation, or structures.

Barriers that pass the test requirements in AS/NZS 3845 – 1999 may be approved for use by road authorities. The tests involve a standard test vehicle impacting a barrier with a generally flat surface in front of the barrier and behind the barrier. Whilst it is preferable that this condition is replicated in practice this is not always possible (e.g. where it is necessary to provide kerbs).

The lateral position of a barrier is influenced by the:

- road cross-section (e.g. need for shoulder and/or kerb)
- barrier-to-hazard clearance
- trajectory of vehicles when crossing kerbs and slopes
- desire to avoid nuisance damage.

Figure 6.2 shows a typical lateral location of a barrier in the verge of a road. It can be seen that the position of the barrier may be dependent on the:

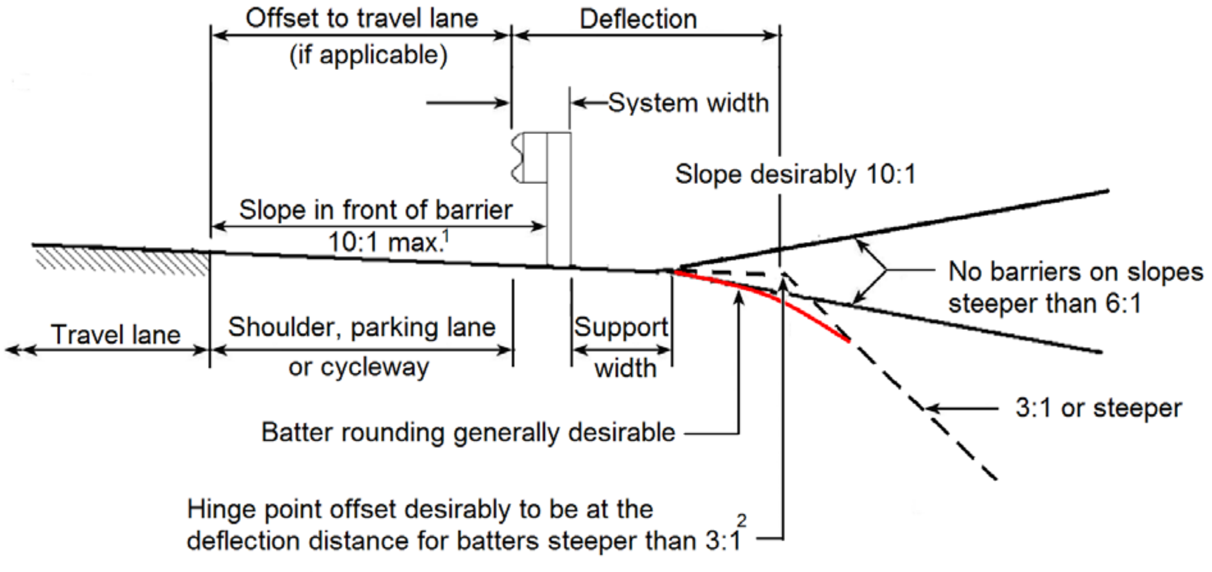
- offset to travel lane
- system width
- support width.

In some cases the distance between the edge of the travel lane and the hazard may be limited in which case the designer will have to consider how the available space will be best utilised and what type of barrier is most suitable for the particular situation.

Sections 6.3.5 to 6.3.12 discuss the key factors to be considered in determining the appropriate lateral location for a barrier situated in road verges and medians. Figure 6.2 illustrates some of the cross-section elements relating to verges.

The area between the traffic lane and the front face of a non-rigid road safety barrier should be a trafficable surface with a crossfall ≤ 10:1. The area between the face of the barrier, to the full extent of the working width, should be in accordance with the barrier manufacturer’s specifications.

Figure 6.2: Verge barrier location



Notes:

1. *This slope is usually determined by the crossfall of the shoulder or lane. Details of crossfall and batter rounding are provided in Section 4 of the* Guide to Road Design – Part 3: Geometric Design *(Austroads 2009b).*
2. *The offset to the hinge point may be reduced where there is no other option.*

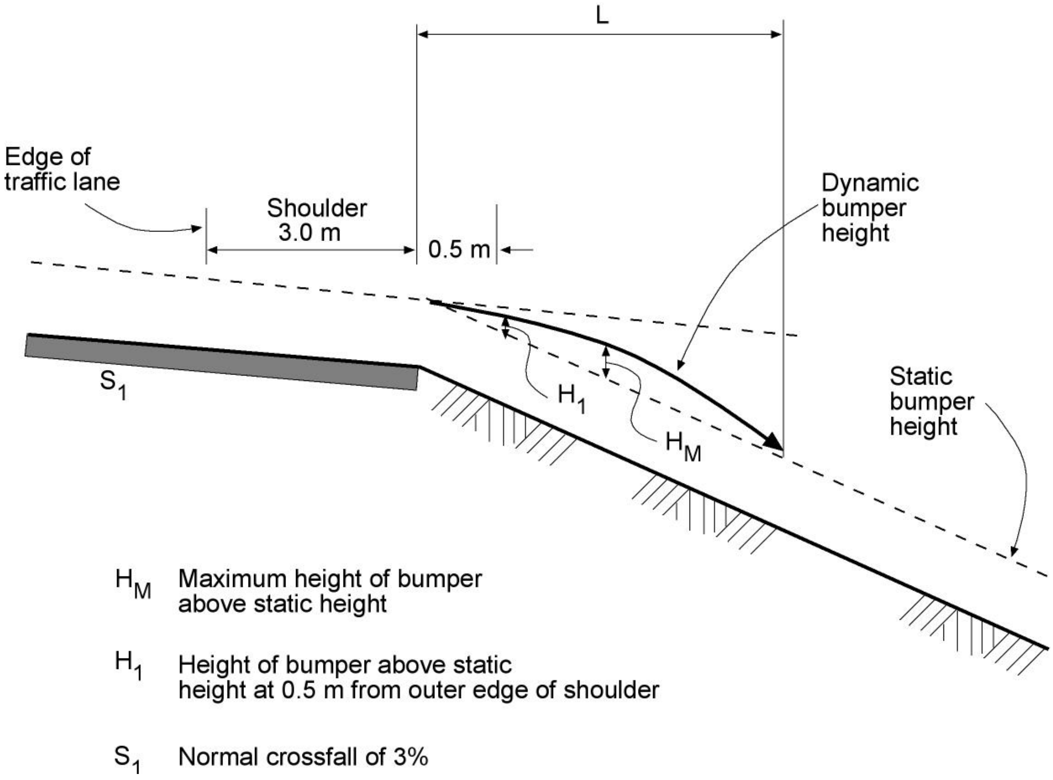
Source: Based on RTA (2008).

When a vehicle passes over a slope or kerb it may follow a trajectory that might influence the height required for the safety barrier, should it be necessary to place a barrier on the embankment slope or some distance behind the kerb. The lateral position of the barrier may therefore be restricted when it is located:

- on embankment slopes
- adjacent to kerbs
- on cutting slopes
- within medians.

Figure 6.3 illustrates an example of a vehicle trajectory over an embankment slope where a barrier placed within the distance ‘L’ may need to be higher in order to contain a car. Commentary 12 provides further information on the subject and examples of trajectories and heights of the trajectories where cars traverse embankments, kerbs and cutting slopes. Commentary 12 also illustrates suggested locations where a barrier should preferably not be erected.

Figure 6.3: An illustration of bumper height trajectory characteristics over a fill embankment



Source: Based on RTA (1996).

6.3.5 Offset to Travel Lane

Road user requirements

The offset from the edge of the travel lane to the face of the barrier will depend on the type of road and the use of the road. Rural roads generally require shoulders that have several purposes whilst urban roads may require the provision of parking lanes, bus lanes or bicycle lanes. Guidance on cross-section requirements is provided in the *Guide to Road Design – Part 3: Geometric Design* (Austroads 2009b).

When roadside features such as bridge railings, parapets, retaining walls, fences or roadside road safety barriers are located too close to traffic, drivers in the adjacent traffic lane tend to reduce speed, drive off-centre in the lane, or move into another lane. The distance from the edge of the traffic lane beyond which a roadside object will not be perceived as an obstacle and result in motorists changing their behaviour is called the shy line. Where possible, road safety barriers should be located outside of the shy line, particularly where relatively short lengths of barrier are used.

Depending on circumstances it may be preferable to provide the same shoulder width (if applicable) adjacent to barriers as is provided elsewhere along a road. However, jurisdictional practice may require consideration to be given to the provision of a wider shoulder (e.g. 3 m to 4 m from the edge of the adjacent traffic lane to the barrier) in order to provide space for nearside vehicle doors to be opened or to provide space for maintenance vehicles to stand clear of the traffic lane. This width enables the doors of vehicles to be opened clear of traffic lanes in the case of non-discretionary stops.

Where space is limited, and discretionary parking or emergency stopping is not essential, it may be preferable to provide a reduced shoulder width in front of the barrier, provided that the shy line principle is given adequate consideration. Designers should comply with any local policy jurisdictions may have regarding the minimum offset to road safety barriers. Consideration should be given to sealing the shoulder for its full width where road safety barrier is installed at the edge of the shoulder.

Designers should be aware of the following risks if barriers are placed close to the travel lane:

- There is an increased risk of sideswipe crashes if narrow lane widths are used next to barriers. This occurs because drivers tend to move away from the barrier and may encroach into adjoining travel lanes.
- Drivers will travel at moderate speed close to long lengths of barrier; however, this is generally only successful in a high-stress driving environment (e.g. tunnels and bridges) where drivers are attentive and ready to react quickly to risks.
- Driving close to barriers increases the stress of the driving task and cannot be sustained for long periods.
- Barriers close to the travel lane have a high probability of nuisance impacts that will increase the need for maintenance and repair. Barriers that remain operational after an impact should be used where there is a high risk of repeat impacts before repairs can be made.
- Short lengths of barrier close to the travel lane have a high risk of being impacted because of driver fatigue or inattentiveness.

Maintenance access

In some situations (e.g. high-volume, high-speed roads) consideration may be given to offsetting the safety barrier a sufficient distance from the road (e.g. 4 m) to enable a road maintenance truck to stop clear of general traffic whilst inspecting or undertaking routine maintenance of safety barrier or other roadside features.

Barrier setback from kerb

As a general principle, it is preferable that surface conditions in front of and beneath barriers should be similar to the conditions under which barriers are tested (i.e. relatively flat). While this is usually possible on roads that have a rural cross-section there are instances where kerbs are required, and urban roads almost always have kerbs.

In rural situations drainage should be designed so that it is not necessary to place a kerb under or in front of a road safety barrier. The provision of kerbs in close proximity to barriers should only occur in urban situations where a kerb is necessary and the speed environment is ≤ 80 km/h.

Where it is necessary to place a barrier close to a kerb it is preferable that the face of the barrier is aligned vertically with the face of the kerb. Where this is not practicable because of design constraints, or there is a high probability of minor nuisance vehicle impacts (e.g. where the kerbside lane is narrow) the barrier may be offset a small distance behind the kerb as shown in Figure 6.4. This offset may be determined by footing requirements or the need to avoid nuisance impacts as detailed in Table 6.3.

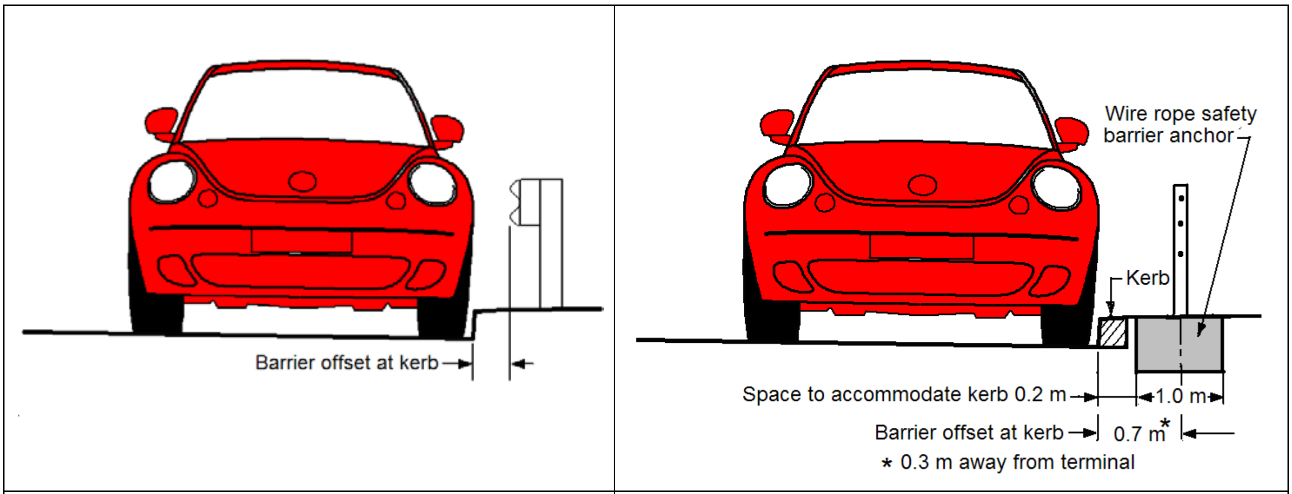
For new roadworks where road safety barrier is used in close proximity to a kerb it is desirable that a semi-mountable kerb profile is used.

Offsets greater than those shown in Table 6.3 may have an advantage in that they can:

- reduce nuisance impacts on the barrier
- avoid the situation where vehicles that have impacted the barrier are disabled in a high-speed travel lane, which increases the risk of a secondary crash.

However, kerbs located in the vicinity of a flexible or semi-rigid barrier can affect the vehicle trajectory and hence the effectiveness of a barrier. For this reason it is suggested that, as a general guide, a barrier (other than a rigid barrier) should not be located between 0.2 m and 3 m (upper limit depends on speed) behind the kerb. Designers should refer also to Commentary 12 where the behaviour of vehicles crossing kerbs is discussed and further guidance is provided on the location of barriers in relation to kerbs.

Figure 6.4: Barrier offset at kerb



(a) Steel beam barrier

(b) Wire rope barrier

Table 6.3: Minimum offsets from kerb to barrier face

Situation	Offset from kerb face to barrier (m)
Wire rope road safety barrier	0.3 m(1) generally over length of barrier Larger offset may be required at terminal to accommodate foundation(1) (e.g. say 0.70 – based on half the anchor width + width of kerb)
Steel rail road safety barrier (e.g. W-beam, Thrie-beam road safety barrier), constrained situation	0.00 (increased nuisance hits may occur)
Steel rail road safety barrier (e.g. W-beam, Thrie-beam road safety barrier), normal situation	0.20
Concrete barrier	0.00 (barrier is the kerb)
Barrier on traffic island	0.20 + bus overhang when a wheel is at the kerb

1. Varies depending on product and foundation required – consult manufacturer's drawings.

Shy line offset

Where long continuous lengths of barrier are used this shy line effect is not so critical, especially if the commencement of the barrier can be gradually transitioned from beyond the shy line. Desirably, the clearance to roadside features should be consistent as this practice reduces driver reaction to isolated objects or features.

AASHTO (2006) suggests that drivers do tend to reduce speed or laterally move their vehicles away from a road safety barrier if it is within a 'shy line offset' distance from the edge of the travelled way. Whilst the shy line offset concept is widely used in western world design guides, the original supporting research is not referenced as it cannot be located.

AASHTO (2006) provides the offset values shown in Table 6.4 and suggests barriers with a lateral offset less than the shy line offset should have a flare on the approach as shown in Figure 6.5.

Table 6.4: Shy line offset values

Design speed (km/h)	Shy line offset (m)
50	1.1
60	1.4
70	1.7
80	2.0
90	2.2
100	2.4
110	2.8
120	3.2
130	3.7

Source: AASHTO (2006).

There is also some evidence available that the presence of a safety barrier may influence the operating speed of traffic. Research (Tay and Churchill 2007) has shown that the mean traffic speed on sections of road with median road safety barriers is higher than similar sections of road without median road safety barriers. Experience in Sweden (Bergh & Carlsson 1999) is that traffic speeds increased on a narrow road after construction of a median wire rope road safety barrier. This research has called into question previous assumptions that drivers will slow down near road safety barriers.

Flaring

Motorists are less likely to perceive roadside barriers to be a hazard if the barrier is introduced gradually to the roadside environment through the use of a ‘flare’. Consequently some end treatments for semi-rigid barrier (i.e. W-beam) are designed to be flared away from the approaching traffic as shown in Figure 6.5. The flare rate is the ratio of the length of the flared part of the barrier (measured parallel to the road) to the barrier offset.

Designers should provide a flare where barriers are within the shy line offset, provided that other design requirements are not compromised (e.g. some road safety barrier terminals need to be parallel to the roadway).

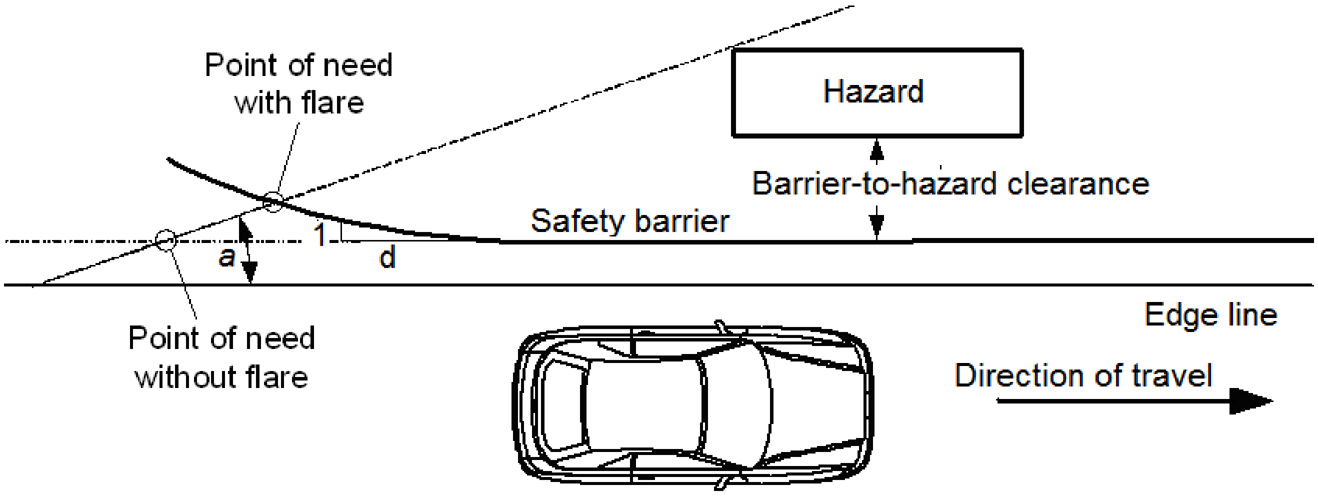
Flaring should be used to:

- locate a barrier terminal further from the travelled path
- minimise shy line effects where a hazard is close to the travelled path
- provide a gradual transition to a major hazard close to the roadway (such as a bridge parapet or railing)
- provide a transition from centre median placement to dual side median placement (refer to Figure 6.10).

The maximum flare rates that should be used on an approach to a road safety barrier are shown in Table 6.5. Caution should be used in applying flaring as barriers are designed to work best with a glancing impact. Flaring may lead to vehicles impacting a barrier at a high angle that will lead to hazardous consequences.

It should be noted that if a flare is used the terminal specified must suit the flare. Practitioners should refer to the manufacturers’ published information for proprietary systems and the relevant road authority information for public domain devices.

Figure 6.5: Detail of flare rate



Note: For angle 'a' refer to Table 6.10.

Source: Adapted from RTA (2008).

The flare rates applied should not enable impacts with the road safety barrier to occur at an angle greater than 25 degrees. Road safety barrier systems are not tested at impact angles greater than 25 degrees as the barrier may rupture or cause excessive vehicle damage and occupant injury at high impact angles.

Table 6.5: Flare rates

Design speed (km/h)	Flare rate for barrier within the shy line offset (d:1)	Flare rate for *rigid* barrier outside the shy line offset (d:1)	Flare rate for *non-rigid* barrier outside the shy line offset (d:1)
50	13:1	8:1	7:1
60	16:1	10:1	8:1
70	18:1	12:1	10:1
80	21:1	14:1	11:1
90	24:1	16:1	12:1
100	26:1	18:1	14:1
110	30:1	20:1	15:1

Source: Based on AASHTO (2006).

It can be seen from Table 6.5 that the flare rate adopted depends on whether the barrier is located within or outside the shy line, and on the type of barrier. The flare rate values indicate a smaller flare angle for both types of barrier when located inside the shy line. Smaller flare angles should be used where extensive grading would be required to ensure a low-angle approach to the barrier from the carriageway (AASHTO 2006).

Flaring of barriers can have the following disadvantages:

- The greater the flare angle the higher the impact angle and the subsequent severity of crashes into that part of rigid and semi-rigid barriers.
- The likelihood of a vehicle being redirected back onto the roadway following an impact with the flared section is increased.

- Higher flare angles may also increase the need for additional earthworks and slope flattening in the area between the roadway and the barrier.

6.3.6 Support Width

The minimum support width required between the rear of the road safety barrier and the hinge point of the batter is shown in Table 6.6. However, on batters steeper than 3:1 it may be necessary to provide structural support to road safety barrier foundations.

Table 6.6: Typical support width

System type	Support width
Wire rope road safety barrier	600 mm
W-beam road safety barrier and thrie-beam	600 mm
Permanent concrete road safety barrier	0 mm where barrier is part of a structure (e.g. retaining wall) Where a concrete barrier is not part of a structure such as a noise wall it must have adequate lateral support either from the pavement and/or its surfacing or the surrounding ground. Depending on circumstances options may include: • setting the base of the barrier into the road pavement • setting the barrier into the asphalt road surfacing • attaching the barrier to an existing road surface through a system of dowels • provision of a foundation to support the barrier profile.

Source: Based on RTA (2008).

Situations sometimes arise where a safety barrier must be provided to shield a foreslope at a site where there are severe lateral constraints. In such cases the designer may consider the options for brownfield sites described in Appendix H.

6.3.7 Deflection Width

The deflection width varies depending on the type of system and the particular product. The significance of deflection width is discussed in Section 6.3.15.

6.3.8 System Width

The width of road safety barrier systems varies depending on the type of system and in some cases the strength required. Details of systems and products approved by the relevant road authority, including the system width, may be obtained from manufacturers' specifications or information published by the road authority.

6.3.9 Barrier Location in Medians

The application of road safety barriers to medians depends on the median width and the cross-section. Section 4.7 of the *Guide to Road Design – Part 3: Geometric Design* (Austroads 2009b) provides guidance on medians and median width. From a barrier treatment point of view, medians are classified in two categories:

- narrow medians in the range 1 m to approximately 4.5 m
    - in urban areas these medians would usually be raised kerb medians and medians painted on the pavement. The 4.5 m limit is loosely based on the practice in urban areas to provide a minimum 1.0 m residual median and a 3.5 m right-turn bay within the median area

- wider medians in the range 4.5 m to 10 m
  - numerous studies have shown that wider medians improve safety and that 90% of errant vehicles deviate less than 15 m from the edge of the carriageway. However, the marginal effect of increased width drops off rapidly (80% of errant vehicle deviate less than 10 m) and, where land is expensive, it is hard to justify widths greater than the minimum
  - in most rural areas the cost of a wide median is small, and wide medians (≥ 15 m) are more usual as they give more scope to the road designer in the treatment of the median and in the location of a barrier. Road safety barriers should be considered where the median width is less than 15 m in order to minimise cross-median crashes
- wider medians are classified in three groups
  - depressed medians, or medians with a ditch section
  - stepped cross-section medians where the separate carriageways are individually graded
  - raised medians.

6.3.10 Narrow Medians

General

At many locations the appropriate treatment is to provide a centrally located barrier, immediately behind the shoulder, capable of being impacted from either side (e.g. urban roads where space is limited). Rigid barriers are often chosen in these situations but back to back semi-rigid barrier or flexible barrier may be used where the dynamic deflection can be contained within the median width so that an unacceptable risk does not eventuate for opposing traffic. Typical profiles of median barriers for use in narrow medians are shown in Figure 6.6. Appropriate end treatments must be used to suit each type of barrier and situation (i.e. width available and behaviour of end treatment on vehicle impact).

Figure 6.6: Examples of road safety barriers for use in narrow medians

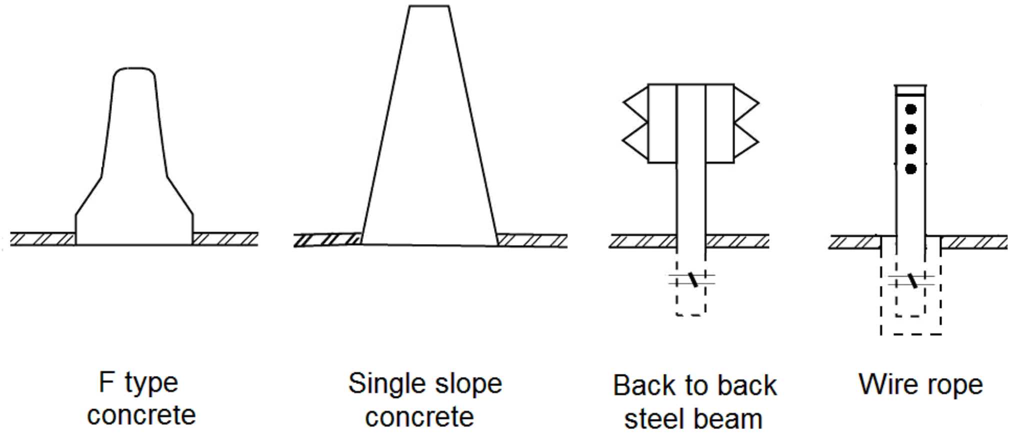
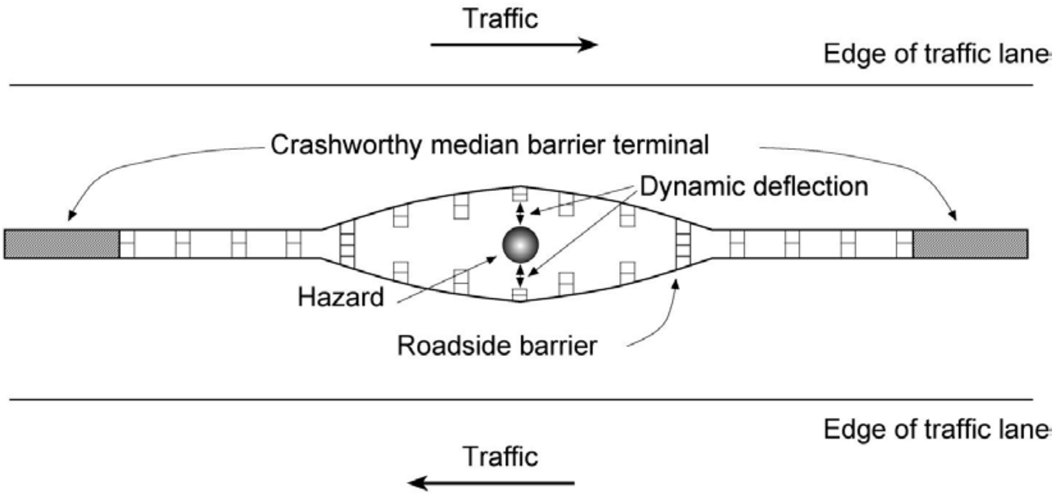


Figure 6.7 details how a rigid object such as a bridge pier can be shielded in a narrow median. The treatment will differ depending on whether the barrier only shields an isolated object or whether it is to be incorporated into a longer barrier system. Where the median is wide enough, a flexible or semi-rigid barrier is preferred.

Figure 6.7: An example of a barrier layout for shielding a rigid object in a median



Note: Designers should also investigate the use of a crash attenuator to shield the hazard.

Minimum width of median

The factors to consider in the determination of minimum widths for medians with barriers are:

- the width of system or width of terminal, whichever is greater
- an allowance for permanent deformation of the system on straights or curves
- whether or not the damaged barrier components and debris will be contained within the median area following impact
- the shoulder width required for delineation and accommodation of drainage grates
- an allowance for sight distance on curves
- the deflection width of the barrier
- stormwater capacity of the median drain.

It is preferable that deflection is contained within the median. However, in constrained situations where this is not possible the deflection may be allowed to encroach into the opposing traffic lanes but only if a risk calculation demonstrates that the level of risk is acceptable to vehicles travelling in the opposing direction. Appendix H provides some information on the use of wire rope safety barriers in narrow medians.

When specifying barriers for narrow medians it is essential that appropriate approach delineation and signage is included. For guidance on minimum median width designers should refer to Section 4 of the *Guide to Road Design – Part 3: Geometric Design* (Austroads 2009b).

6.3.11 Wider Medians

General

The most desirable median is one that is relatively flat (slopes of 10:1 or less), free of hazards and wide enough to enable virtually all errant vehicles to come safely to rest without encroaching into the opposing carriageway or having to be contained by a barrier. To fulfil this objective, a median would have to be very wide and this width is often impracticable. If a barrier is necessary, the most desirable situation is that it is placed in the middle of a relatively flat median (slopes less than 10:1).

When the desirable conditions cannot be achieved, and a barrier is justified based on median width or the presence of non-recoverable slopes, it is necessary to consider the placement of the barrier to achieve the best outcome. This section shows options for the placement of barriers in three basic types of wide median cross-sections, namely depressed, stepped and raised. Considerations associated with each type are summarised below. It should be noted that rigid barrier should not be used in the middle of wide medians (i.e. greater than 3.0 m to 4.0 m from the edge of the traffic lane) because of the likelihood of higher impact angles and resultant higher severity of impacts.

A wire rope barrier located on both sides of the median has the advantage that it maximises the opportunity to contain deflections within the median. However, a central location has the advantages in that:

- debris from damaged barriers is less likely to encroach into the carriageway
- sight distance past the barrier on curves is maximised
- the barrier sustains less nuisance impacts than a barrier on the side of the median
- the cost is less than a barrier on both sides of a median.

Depressed median

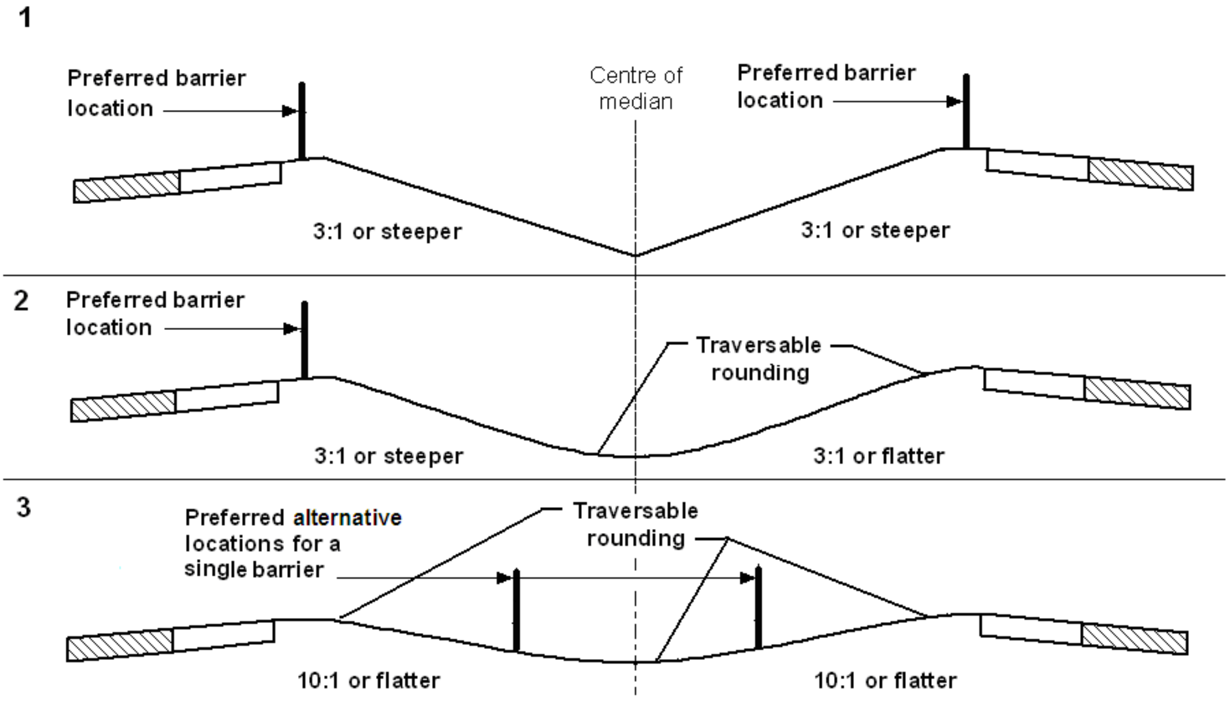
The appropriate location depends on the batter slopes in the median as shown in Figure 6.8. For illustration 1, barriers may be required on both sides of the median adjacent to the shoulder, because of the non-recoverable slopes.

Illustration 2 relates to the situation where the median has a critical slope on one side and a non-critical slope on the other. In this case vehicles in the carriageway adjacent to the critical slope are protected by a safety barrier whereas errant vehicles from the opposing carriageway will traverse the non-critical slope and come to rest in the median. It is important that the median drain has a traversable shape (refer to Sections 4.6.1 and 4.6.3 of the *Guide to Road Design – Part 3: Geometric Design* (Austroads 2009b).

Where slopes in the median are 10:1 or flatter a barrier may be located near the centre of the median as shown in illustration 3. The deflection of the barrier used at this location should be accommodated within the median. It is not generally desirable to locate the barrier in the drain at the centre of wider medians because of the potential for debris to accumulate around the barrier and adversely affect flow within the drain. There is also potential for the post foundations to be affected due to sodden soil within the drain.

Where a barrier is located in accordance with illustration 3 it is important that the invert of the drain is designed (e.g. with gentle rounding) so that the performance of the barrier is not adversely affected (e.g. impact occurs at the wrong height and wheel is captured under barrier).

Figure 6.8: Depressed median barrier locations



Notes:

With respect to illustration 3 where one barrier is placed near the centre of the median it should be located to one side, preferably out of the width generally required for drainage.

Where the site is suitable (i.e. sufficient median width) consideration may be given to offsetting the drain to allow central location of the barrier.

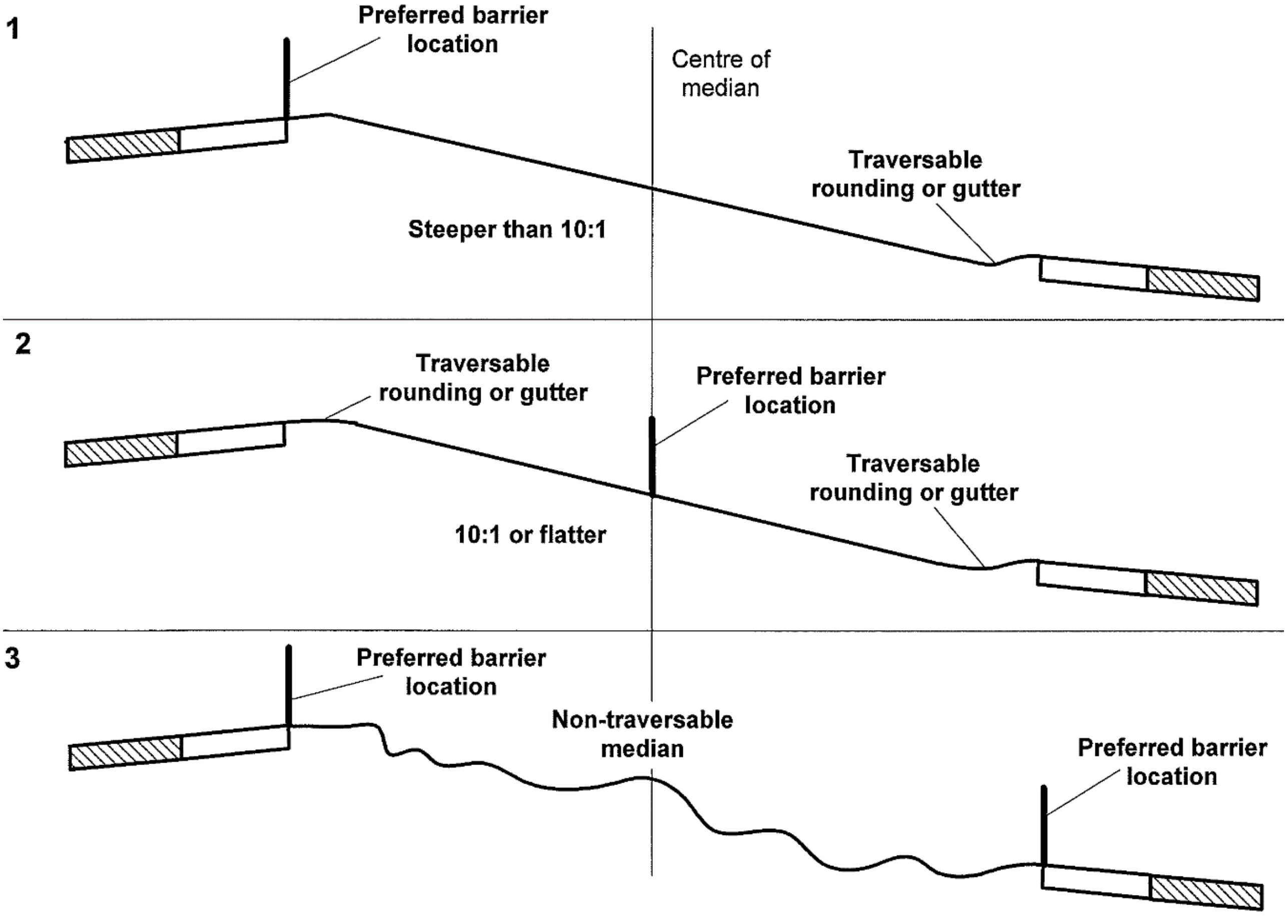
Source: Based on RTA (2008).

Stepped median

The appropriate locations of barriers in stepped medians are shown in Figure 6.9. Where the slope of a stepped median is steeper than 10:1 (illustration 1) and it is considered that a vehicle could run down a recoverable but relatively steep batter and into the opposing carriageway a median barrier should be installed adjacent to the shoulder.

For smooth batters that are flatter than 10:1 a barrier may be placed in the centre of the median as shown in illustration 2. Where the median is rough or not firm and not traversable, barriers should be placed adjacent to each carriageway (illustration 3). It is not unusual for stepped medians to incorporate a retaining wall on the low side. If this is the case the face of the wall on the traffic side should be contoured to the shape required by the road authority (e.g. single slope concrete barrier, F-type barrier etc.).

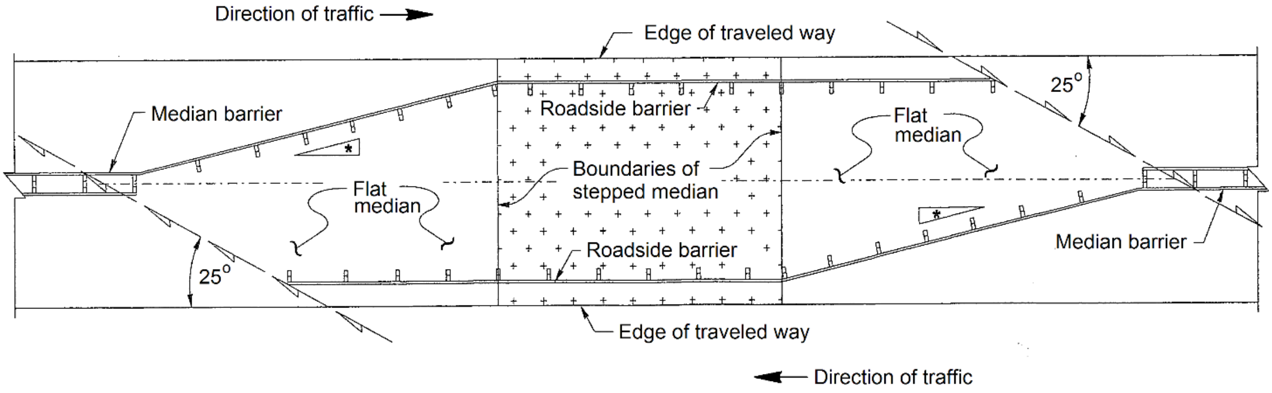
Figure 6.9: Stepped median barrier locations



Source: RTA (2008).

Figure 6.10 illustrates the recommended placement of the barriers upstream and downstream of a stepped median, in order to transition from a centrally located barrier to barriers located near the edge of the road. This corresponds to illustration 3 in Figure 6.9. In this situation, the barrier is split and most median barriers can be split this way.

Figure 6.10: Example of a split median barrier layout and transition



** Flare rates should not exceed suggested limits (refer to Table 6.5).*

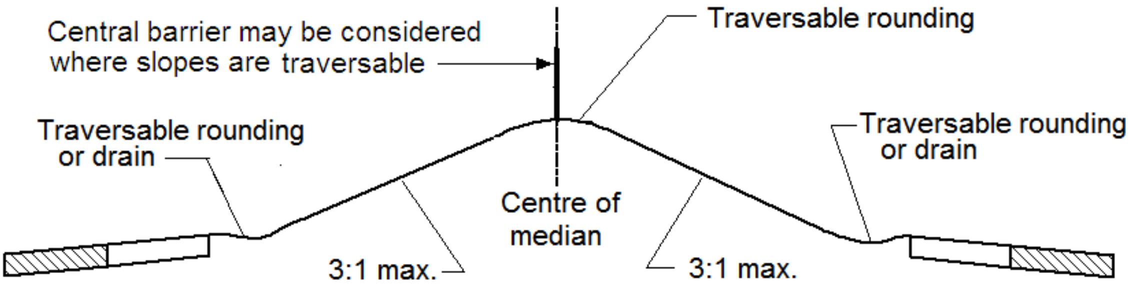
Source: AASHTO (2006).

Raised median

A median that is raised substantially at its centre is illustrated in Figure 6.11. Placement criteria for median barriers on this cross-section are not clearly defined. Research has shown that this cross-section type, if high enough and wide enough, can redirect vehicles impacting at relatively shallow angles. However, this type of median design should not be construed to be a barrier or to provide positive protection against cross-median crashes.

If the slopes are traversable and it is considered that a vehicle could pass over the apex of the median, a non-rigid median barrier may be placed at the apex of the cross-section. For non-traversable slopes (e.g. rough rock cut), a barrier should be placed adjacent to the shoulder of each carriageway. If retaining walls are used adjacent to each carriageway, it is recommended that the base of the wall be constructed to the external shape of the preferred standard concrete barrier.

Figure 6.11: Raised median barrier locations



6.3.12 Step B4 – Determine the Barrier-to-hazard Clearance

The barrier-to-hazard distance is the minimum clearance available between the proposed face of the road safety barrier and the face of the hazard. It is established either from the design plans or site measurements. The barrier-to-hazard clearance defines the envelope available for designing a road safety barrier.

6.3.13 Step B5 – Determine the Barrier Containment Level Required

General

The containment level relates to the objectives for providing the barrier (Section 6.3.3), the class of vehicle that must be contained and corresponding barrier test levels (AS/NZS 3845 – 1999). For example the containment level may be chosen to protect:

- errant vehicle occupants
- a vital piece of infrastructure such as an electrical sub-station or a bridge pier from impact by a heavy vehicle
- an establishment such as a childminding centre that is in a vulnerable situation with respect to errant vehicles.

Designers should refer to AS/NZS 3845 – 1999, policy information from the relevant jurisdiction and to barrier product information available from suppliers to ascertain the required containment level and the type of barrier required.

In the absence of jurisdictional policy on the containment level required for particular situations the containment level may be determined by taking into account the:

- design vehicle to be retained by the road safety barrier
- speed environment of the road safety barrier site.

Road databases or traffic measurements can be used to determine the volume of heavy vehicles that use the road and whether or not heavy vehicles are to be used as the design vehicle. This decision will also be based on the consequences of a truck or bus impact.

Design for heavy vehicles

When considering the adoption of a heavy vehicle as the design vehicle, it should be noted that:

- road safety barriers suitable for all trucks are rarely used and are expensive
- a heavy vehicle will not be contained by a normal road safety barrier
- a car may be extensively damaged by impact with a barrier designed for trucks.

Except for barriers associated with bridges (refer to AS 5100.1 – 2004), and other situations where the consequences of vehicles leaving the road are extreme, road safety barriers are not normally designed to contain van or tanker type semi-trailers (TL5 and TL6). This design limitation has been practised primarily because of the relatively low volumes of these vehicles on many roads and the high cost of providing barriers to contain them. The increased severity of passenger car crashes into high-containment barriers is also an important consideration. Designers should therefore consult any jurisdictional policy that may be available with respect to the use of high-containment barriers on their road networks.

Where a risk assessment indicates that the run-off-road risk associated with heavy vehicles is particularly high, a barrier meeting TL5 or TL6 may be considered. If available, local information on truck encroachment frequency should be considered. However, a decision to design for heavy vehicles should be largely based on consideration of the existence of particular hazards where the consequences of a heavy vehicle running off the road would be catastrophic, for example:

- A heavy vehicle falling from a bridge or embankment onto a passenger railway line or onto a major road, causing multiple fatalities in many vehicles plus significant societal disruption.
- A heavy vehicle impacting a water or steam pipeline, electrical transmission tower, or the like where major disruption to supply, or other consequential damage, such as fire or contamination could occur.
- A heavy vehicle impacting the supports of a structure, such as a bridge or pedestrian overpass, causing the structure to collapse onto the road. This would be catastrophic if there were numbers of people on the structure or if the collapse impacted vehicles or pedestrians on the road and/or caused long-term transport disruption.
- A high occupancy vehicle, such as a bus, falling into deep water from a bridge or embankment or over a drop of sufficient height, killing many of the passengers in the vehicle.
- A heavy vehicle leaving the road at a curve and impacting a community, commercial or residential building (e.g. a school or playground located beside the road). This would be catastrophic if there were significant numbers of people in or around the building.
- A heavy vehicle unable to stop at the base of a long downgrade colliding with other vehicles or buildings. This would be catastrophic if there were significant numbers of people in or around the building.

Designers should consider the likelihood that a heavier barrier, although not required initially, may be required at particular sites during the life of a project. It may be the case that the initial stage of a project requires barriers that will contain a passenger car, but future widening of the carriageway will require a heavier barrier to shield the bridge piers from heavy vehicles. This may also apply where it is known that land use will change adjacent to the road in future and the level of risk may then be such that a high-containment barrier will be required. In such cases designers should ensure that the ultimate barrier requirements can be accommodated.

In some situations there is a need for two levels of protection, the first to protect the errant vehicle occupants, the second to protect a vital piece of infrastructure from impact by a heavy vehicle or to address the risk of high severity crashes involving buses. Two levels of protection can be achieved by placing a flexible road safety barrier in front of a rigid road safety barrier as discussed in Section 6.3.14 (*Barriers for heavy vehicles)*.

In cases of brake failure on downgrades, safety ramps and arrester beds may be considered as possible measures.

6.3.14 Step B6 – Choose the Barrier Type

Key barrier requirements

Barriers used in Australia and New Zealand should comply with the guidelines or product acceptance criterion established by the relevant national or state road authority which are based on the requirements of AS/NZS 3845 – 1999. In addition, only road safety barrier products accepted by the relevant road authority should be used.

The main parameters to consider when selecting a road safety barrier are:

- the speed environment of the barrier site
- the containment level required
- that it has a dynamic deflection that will fit within the working width
- the terminals are suitable for the site.

There are other factors that may be considered in selecting an appropriate type of barrier, either from a general asset management or environmental perspective, or in relation to a particular site (refer to Section 6.2).

Types of barrier

Road safety barrier systems can generally be divided into three broad types comprising flexible, semi-rigid and rigid barriers. As a general principle, if it is practicable to meet the requirements of the following guidelines, the more flexible barrier should always be used as this minimises the severity of any vehicle impacts with the barrier. However, flexible barriers have relatively large deflections which may render them unsuitable in some situations. In some cases a barrier that will contain large heavy vehicles may be required and this will be reflected in the containment level specified.

Special barrier designs and modifications to existing designs have been developed for use where:

- there is a need to cater for vulnerable road users (i.e. motorcyclists and cyclists)
- the aesthetic appearance of the roadside is important.

In general, flexible barriers comprise tensioned wire ropes, semi-rigid barriers have horizontal steel beams and rigid barriers are constructed with concrete. Examples are shown in Figure 6.12, Figure 6.13 and Figure 6.14 respectively whilst the profiles of semi-rigid and rigid barriers are illustrated in Figure 6.15 and Figure 6.16. For details of barrier profiles and materials (e.g. concrete strength and composition) designers should refer to the relevant jurisdictional or manufacturers' standard drawings and specifications.

The type of rigid barrier profile used varies between jurisdictions. The single slope and vertical wall barriers have an advantage in that the road can be resurfaced without affecting the profile or requiring expensive resetting of the base level of the barrier. This a key reason for their use in some jurisdictions. There are two types of profile that have the same height but different slopes on the wall.

To function correctly rigid barriers require some lateral restraint which may require a foundation (refer to Table 6.6 regarding support width). Where drainage is required at the barrier location (e.g. in a narrow median) it is important the drainage design is coordinated with the barrier design (i.e. location and depth of pipes, pits, etc.).

Figure 6.12: Examples of flexible (i.e. wire rope) barrier

Figure 6.13: Semi-rigid barrier

Figure 6.14: Rigid barrier

Figure 6.15: Examples of profiles of semi-rigid barriers

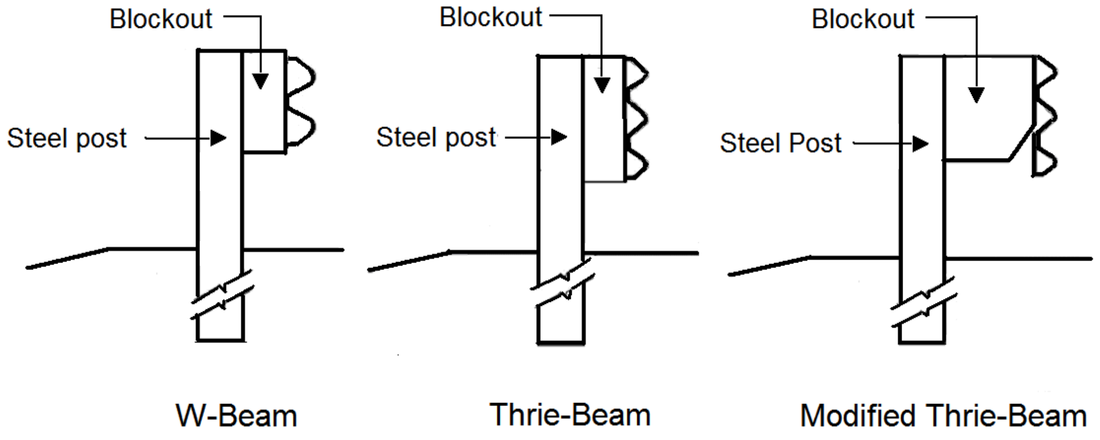
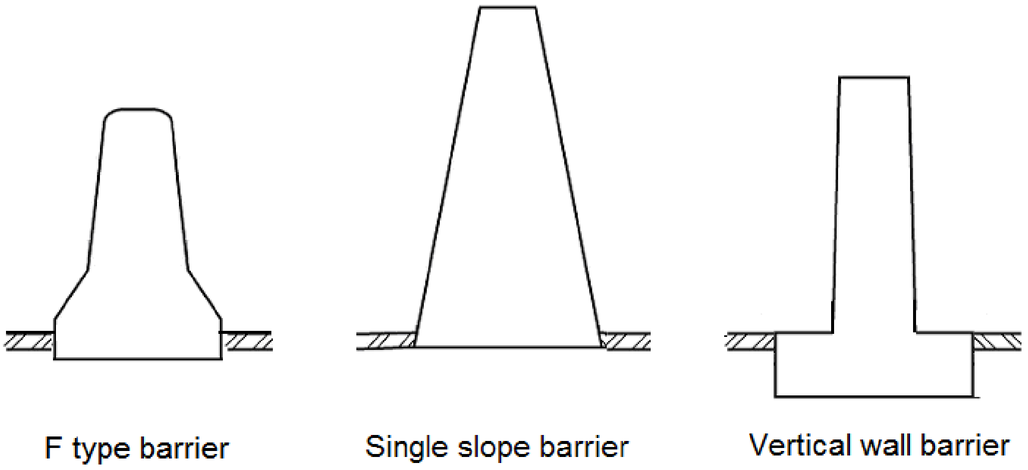


Figure 6.16: Examples of profiles of rigid barriers



Barrier height

Barrier height is critical in that a rail installed too low is likely to cause errant vehicles to pass over the top of (i.e. vault) the barrier, whereas a rail that is too high is likely to cause errant vehicles to snag on posts or even pass under the rail. The heights of the various barrier systems have been established through crash testing using appropriate test vehicles and therefore all barriers should be installed at a height that complies with the requirements of the relevant road authority. These requirements take into consideration AS/NZS 3845 – 1999 for public domain barriers and manufacturers' specifications for proprietary products.

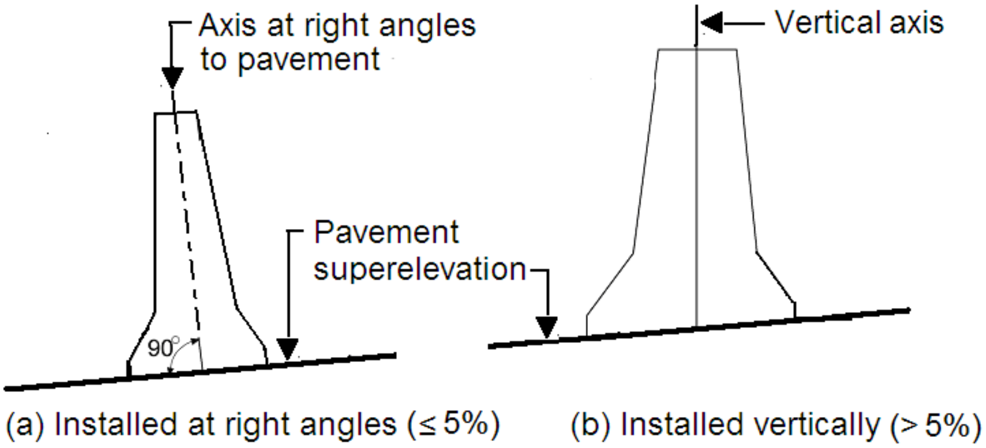
The height of a road safety barrier is measured as follows:

- Steel rail barrier height is measured from the pavement level to the top of the rail and is the same with or without a kerb below the barrier.
- Wire rope barrier height is measured from the surface immediately below the wire ropes. When a wire rope barrier is erected above, or next to a pavement without kerbs, the height is measured from the pavement. When a wire rope barrier is erected on a median or verge, behind a kerb, the height is measured from the finished surface (generally a kerb height higher than if it were measured from the pavement).

- Concrete barriers should be mounted on the pavement and the height is measured from the pavement level at the bottom of the barrier to the top of the barrier. Concrete barriers generally need to be perpendicular to the pavement, not vertical, to ensure the angles on the face are at the correct height in relation to the pavement. If retrofitting a concrete barrier on an existing kerb line the kerb should be removed to ensure the heights of the angles in the barrier face are at the correct height above the pavement.

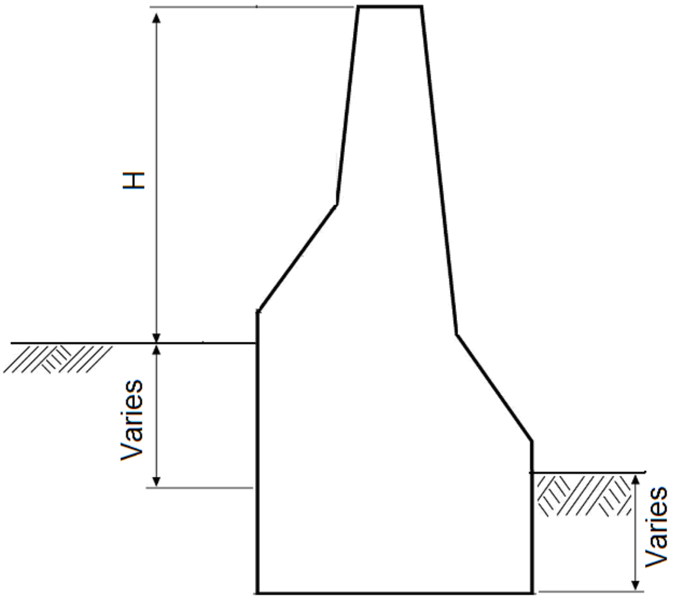
Where a rigid barrier is erected on a superelevated roadway the options illustrated in Figure 6.17 should be considered. Practice may vary between jurisdictions but it is suggested that a rigid barrier should be installed at right angles to the pavement where the superelevation is 5% or less and vertically where the superelevation exceeds 5%.

Figure 6.17: Preferred installation of rigid barrier on a superelevated roadway



Where a concrete barrier is erected in a narrow median on independently graded duplicated carriageways the arrangement shown in Figure 6.18 may be considered. This treatment requires a foundation designed to provide for the difference in level.

Figure 6.18: Rigid barrier in narrow median with independently graded carriageways



Barrier design criteria

Barrier design criteria must be obtained from information published or provided by the relevant road authority. Design values that need to be matched against the site constraints include:

- design speed
- tested containment
- deflection
- system width
- point-of-need
- minimum length between terminals
- allowable terminals
- anchor requirements
- allowable use on medians
- minimum median width
- minimum offset to travel lane
- embankment slope limit
- ability to contain multiple impacts
- foundation conditions
- vulnerable road user limitations
- allowable use in pedestrian areas
- allowable use in gore areas.

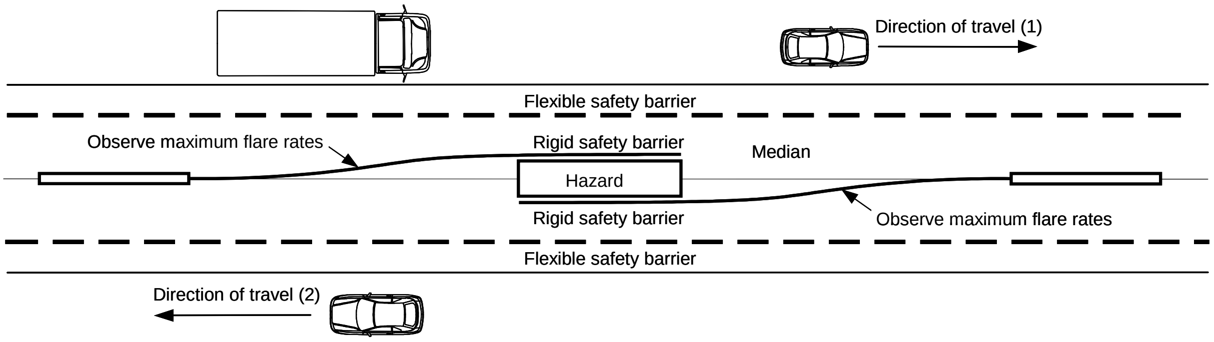
Barriers on structures

Barriers on structures in Australia should be designed in accordance AS 5100.1 – 2004. In New Zealand, designers should refer to the *Bridge Manual* (Transit NZ 2003).

Barriers for heavy vehicles

Factors that should be considered in the determination of the required containment level for barriers are discussed in Section 6.3.13, including the option of a two-stage barrier system. In most cases a single barrier to contain the design vehicle will be chosen. However, where a two-stage barrier system is appropriate a layout similar to that illustrated in Figure 6.19 may be used.

Figure 6.19: Two-stage protection layout



Source: RTA (2008).

The following issues must be considered when designing two-stage protection:

- Design requirements for working width, length of need and minimum length of barrier must be met. The traffic face of the rigid barrier must be offset from the face of the bridge pier to accommodate working width.
- The structural design of the bridge pier may require a gap between the rigid barrier and the bridge pier, or the rigid barrier may be an integral part of the bridge pier, if the pier has been designed for high-mass, high-speed impact loadings.
- The rigid barrier must be designed to ensure it does not overturn when impacted by errant large mass vehicles.
- It is preferable that the rigid barrier be aligned parallel to the carriageway, rather than flared. This will facilitate extension of the rigid barrier if additional lanes are added in the future.
- In some situations the end of the rigid barrier may require a crash attenuator (refer to individual road authority requirements).
- Wherever possible, the offset between the flexible barrier and the rigid barrier should be more than the working width of the flexible barrier.
- A cross slope of 10% or flatter should be provided between the flexible and the rigid barrier.

Barriers across culverts

Options that may be considered for placing road safety barriers across culverts where posts cannot be used are:

- thrie-beam with a span up to 4.0 m with a 3.5 mm thick rail or nested rail
- bridge style barrier
- strengthening the rail and omission of posts.

Posts may be omitted and a stronger rail used if the integrity of the road safety barrier system can be verified. For example, FHWA acceptance letter HMHS-B58 agrees to the use of a W-beam nested rail over a span of 7.62 m and designers may refer to the letter for the details of the treatment, particularly post spacing either side of the span and the length of nesting (FHWA 1999).

It should be noted that the culvert behind the road safety barrier should desirably be wide enough to accommodate the dynamic deflection of the options described.

6.3.15 Step B7 – Determine Dynamic Deflection

When a vehicle strikes a road safety barrier the dynamic deflection of a barrier varies according to the characteristics of the impacting vehicle, impact speed, angle of impact and the characteristics of the barrier system. Sufficient dynamic clearance should be provided between the face of a barrier and a hazard to accommodate the appropriate dynamic deflection. For design purposes dynamic deflections should be determined from information available from the relevant jurisdictional publications and other advice (e.g. product specific specifications that may be based on tests and manufacturers' advice).

The deflection information given in Table 6.7 is only suitable for concept design. More detailed deflection data for use in detailed design should be obtained from the relevant road authority guidelines or specific product information. If the envelope for deflection is too small to accommodate the dynamic deflection of a flexible barrier, then a semi-rigid or rigid barrier must be used.

Designers may refer to dynamic deflection information resulting from tests on a particular barrier. However, these tests are often conducted on a relatively short length of barrier and the effect of longer lengths and other factors on deflection should be taken into account wherever possible. Designers may therefore refer to research on particular types of barriers. For example, in the case of wire rope barriers research is available that provides correction factors to take account of aspects such as barrier length, horizontal curvature and temperature (Alberson et al. 2003).

Table 6.7: Indicative deflection for concept/feasibility design

Barrier type	Indicative deflection caused by 2000 kg vehicle, at 100 km/h impacting at 25 degrees (m)
Work zone barrier	Refer to relevant road authority
Wire rope road safety barrier	1.7 - 2.2 (depending on product type)
W-beam road safety barrier	1.4
Thrie-beam road safety barrier	0.9
Type F concrete barrier (permanent system attached to the pavement)	0.0

Notes:

Refer to relevant road authority for product specific deflections for use in detailed design.

The deflections quoted in the table are based on the crash test results which typically involve short sections of barrier (e.g. 100 m).

The deflection of wire rope barrier systems will depend on post spacing, barrier length and road curvature.

Where the barrier type is known designers should check specific product information to determine design deflections.

It should be noted that some semi-rigid systems can be strengthened locally by adding additional posts or by reinforcing the rail element (i.e. using a double beam or nested rails) to shield individual fixed hazards that are within the deflection distance for a single beam barrier. In addition, the deflection of wire rope road safety barrier can also be reduced by adopting closer post spacing. However, it should be noted that the practice of using closer post spacing to reduce deflections is based on a limited number of tests with light European test vehicles. It is not clear how far in advance of the hazard that the reduced post spacing is required for the smaller deflection to be achieved and if the same magnitude of reductions would be achieved with the heavier test vehicles.

6.3.16 Step B8 – Determine Vehicle Roll Allowance and System Width

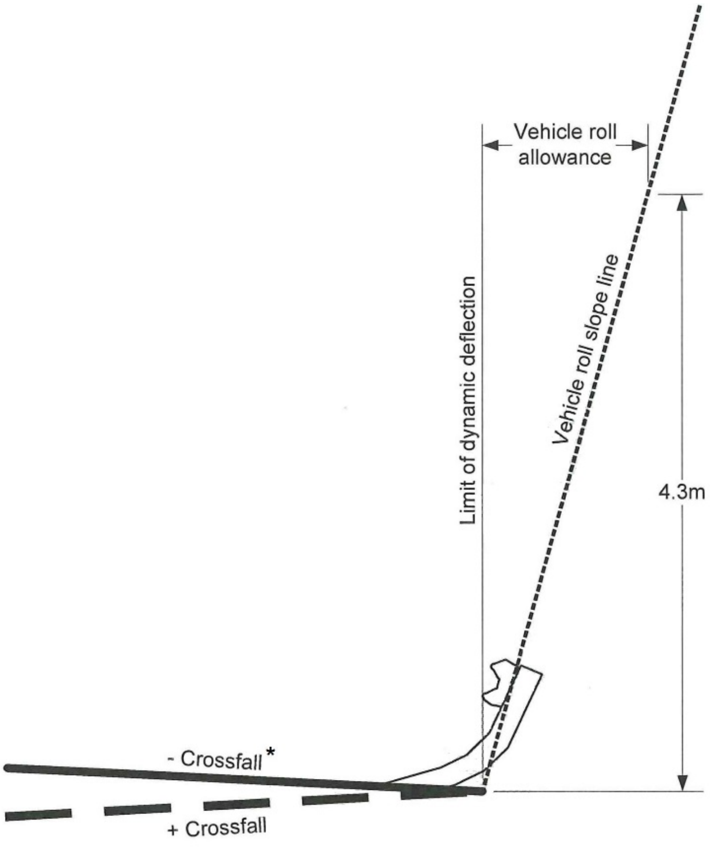
All barrier systems deflect under impact by errant vehicles except for rigid concrete barriers. The behaviour of barriers under impact varies depending on the type of system. The posts in semi-rigid systems act to reduce deflection but may induce more vehicle roll whereas the weaker posts in flexible systems do not restrain the cables under impact and vehicle roll is likely to be less.

Vehicle roll allowance

The vehicle roll allowance concept is shown in Figure 6.20 where the deflection of a semi-rigid barrier is depicted together with an indicative line of the roll experienced by an impacting vehicle. Vehicle roll is significant for high vehicles where the hazard has sufficient vertical height to be within the vehicle roll slope line.

The vehicle roll allowance values shown in Table 6.8 are for a height of 4.3 m above the pavement. These values are based on the vehicle dynamics of a 4.3 m high van type rigid or articulated truck. The vehicle roll allowance values may be interpolated where the hazard is less than 4.3 m high but caution should be applied in their use.

Figure 6.20: Vehicle roll allowance



* It is advantageous if the crossfall slopes away from a vertical hazard (e.g. bridge pier)

Source: RTA (2008).

Table 6.8: Vehicle roll allowance

Vehicle roll allowance at 4.3 m height above pavement (m)															
Design speed (km/h)	**Crossfall (%)**														
	-7	**-6**	**-5**	**-4**	**-3**	**-2**	**-1**	**Flat**	**+1**	**+2**	**+3**	**+4**	**+5**	**+6**	**+7**
40	0.70	0.65	0.60	0.55	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
50	0.75	0.70	0.65	0.60	0.55	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
60	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
70	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.55	0.55	0.50	0.50	0.50	0.50	0.50	0.50
80	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.60	0.60	0.55	0.50	0.50	0.50	0.50	0.50
90	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.70	0.70	0.65	0.60	0.55	0.50	0.50	0.50
100	1.10	1.05	1.00	0.95	0.90	0.85	0.80	0.80	0.80	0.75	0.70	0.65	0.60	0.55	0.50
110	1.20	1.15	1.10	1.05	1.00	0.95	0.90	0.90	0.90	0.85	0.80	0.75	0.70	0.65	0.60

Notes:

Interpolate vehicle roll slope line for objects that are less than 4.3 m high.

The vehicle roll allowance will depend on the height and type of barrier. The values in this table apply to a 710 mm high (approximately) W-beam barrier.

System width

The system width is the overall width of the barrier at the top as shown in Figure 6.2. If the system width is greater than the vehicle roll allowance, the system width will be used in the calculation of working width (Section 6.3.17).

6.3.17 Step B9 – Determine the Working Width

Working width is defined in Section A.4 and illustrated in Figure A 7 of Appendix A. The working width is simply the sum of the dynamic deflection and vehicle roll allowance (or system width if it is larger than the vehicle roll allowance).

6.3.18 Step B10 – Check that the Working Width is Less than the Barrier-to-hazard Clearance

This is a simple step in which working width is checked against the barrier-to-hazard clearance. If the working width is greater than the barrier-to-hazard clearance available the barrier may not prevent an impact with the hazard. In this case designers should consider:

- changing the barrier to a more rigid type
- changing the lateral position of the barrier
- using a two-stage barrier as described in Section 6.3.14 under *Barriers for heavy vehicles.*

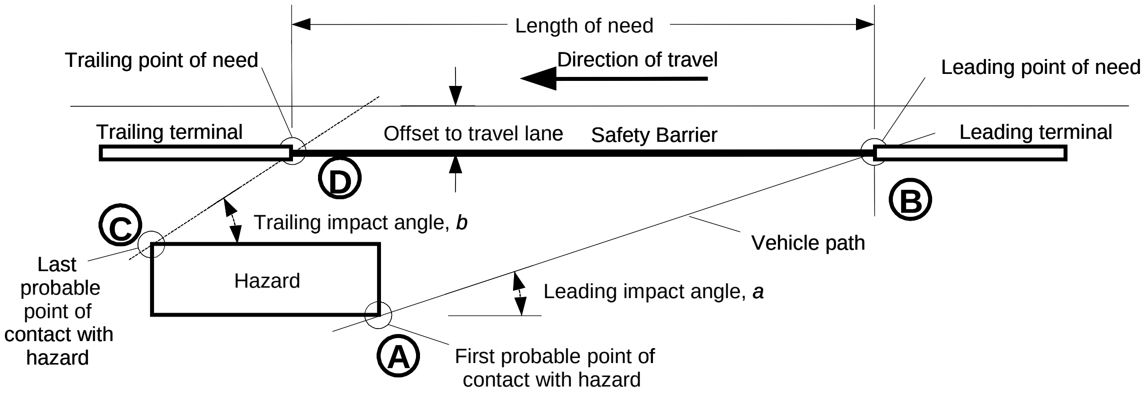
6.3.19 Step B11 – Determine Barrier Points of Need

General

The point of need is the location at which the system (terminals including attenuators) becomes re-directive. The point of need applies to both the leading terminal and the trailing terminal of a barrier. The length of need is the length of barrier required to redirect an errant vehicle and shield the driver from the hazard (i.e. the distance between the points of need). This concept is illustrated in Figure 6.21 for a barrier that could be impacted from a single direction of travel and in Figure 6.22 for a barrier that could be impacted from two directions of travel.

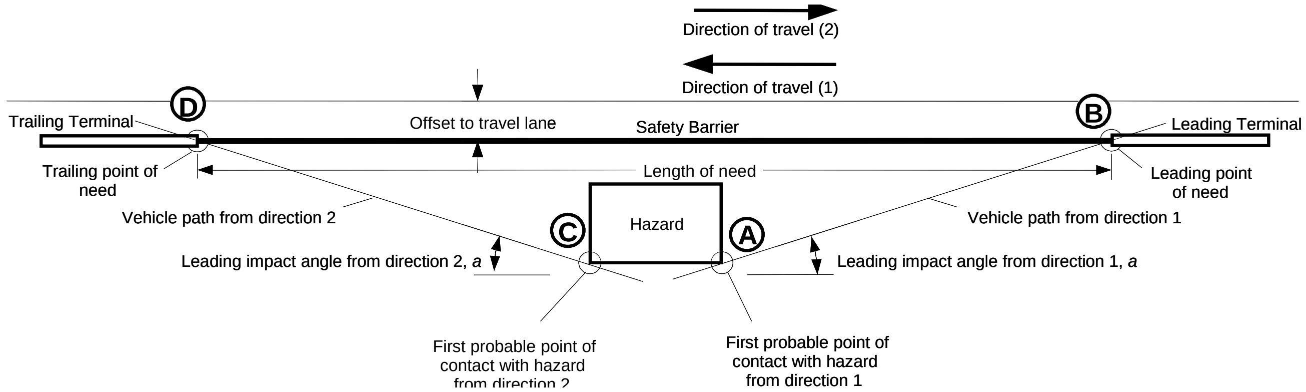
Points B and D in Figure 6.21 and Figure 6.22 represent the leading and trailing points of need respectively, whilst points A and C represent the extremities of the hazard relating to points B and D. The method to establish these points is further explained in text relating to Figure 6.26 which illustrates the angle of departure method of establishing the length of need.

Figure 6.21: Points of need – single direction



Source: RTA (2008).

Figure 6.22: Points of need – two directions



Source: RTA (2008).

Where the test level of a barrier is determined by the level of protection required for a specific hazard, it is implicit that the same level of protection should be provided over the whole length of need associated with that hazard. For example, where a hazard requires TL5 protection, a barrier successfully tested to TL5 must be provided over the full length of need associated with that hazard.

There are two geometric methods used to determine the likely trajectory of a vehicle that leaves the road in the vicinity of a roadside hazard and the length of need required, a method based on run-out length and a method based on angle of departure. The methods result in different lengths. For large widths requiring shielding the run-out method is likely to result in a longer length of need and for narrow widths a shorter length of need compared to the angle of departure method. However, both methods are acceptable for use in Australia and designers should consult the relevant road authority to establish the local jurisdictional practice.

Both methods are described below and worked examples are provided in Appendix K.

Run-out length method

This is the method favoured by some Australian road agencies and the American Association of State Highway and Transportation Officials (AASHTO 2006). The run-out length (L_R) is shown in Table 6.9 and is the length of clear run-out area that should be made available as a passageway for deceleration between the start of the barrier and a non-bypassable hazard. It is the theoretical distance needed for a vehicle that has left the roadway to come to a stop and is therefore dependent on vehicle speed. It is measured from the upstream extent of the obstruction along the roadway to the point at which a vehicle is assumed to leave the roadway, although the actual distance travelled is along the vehicle departure path. Examples of calculations are provided in Appendix K.

Table 6.9: Run-out lengths for barrier design

Design speed (km/h)	Run-out length L_R (m) for AADT range			
	> 6000	2000 – 6000	800 – 2000	< 800
110	145	135	120	110
100	130	120	105	100
90	110	105	95	85
80	100	90	80	75
70	80	75	65	60
60	70	60	55	50
50	50	50	45	40

Note: The figures shown are based in part on the findings of Hutchinson and Kennedy (1966) from their study of freeway median encroachments and in part on driver reaction times and vehicle stopping characteristics for low-speed encroachments. They have been further modified to reduce the lengths of barriers recommended on low-volume roads and streets. Source: (AASHTO 2006).

Straight sections of road

The application of the run-out length method to establish barrier length of need for both traffic approaching in the left lane, and for opposing traffic, is illustrated in Figure 6.23. On a two-lane two-way road, and for medians, these requirements are combined to develop a design layout that protects traffic from both directions. The layout of barriers on straight or nearly straight sections of road is established by applying the following formulae (Equations 3, 4 and 5):

For installations where the barrier is flared (refer to Section 6.3.5):

$$X = \frac{\left[L_A + \left(\frac{b}{a}\right)(L_1) - L_2\right]}{\left[\left(\frac{b}{a}\right) + \left(\frac{L_A}{L_R}\right)\right]} \qquad 3$$

For parallel installations that have no flare:

$$X = \frac{\left[L_A - L_2\right]}{\left[\frac{L_A}{L_R}\right]} \qquad 4$$

The lateral offset, Y, from the edge of the running lane to the beginning of the length of need may be calculated from:

$$Y = L_A - \frac{L_A}{L_R}(X) \qquad 5$$

where

X = the required length of need in advance of the area of concern (hazard)

L_R = run-out length (Table 6.9)

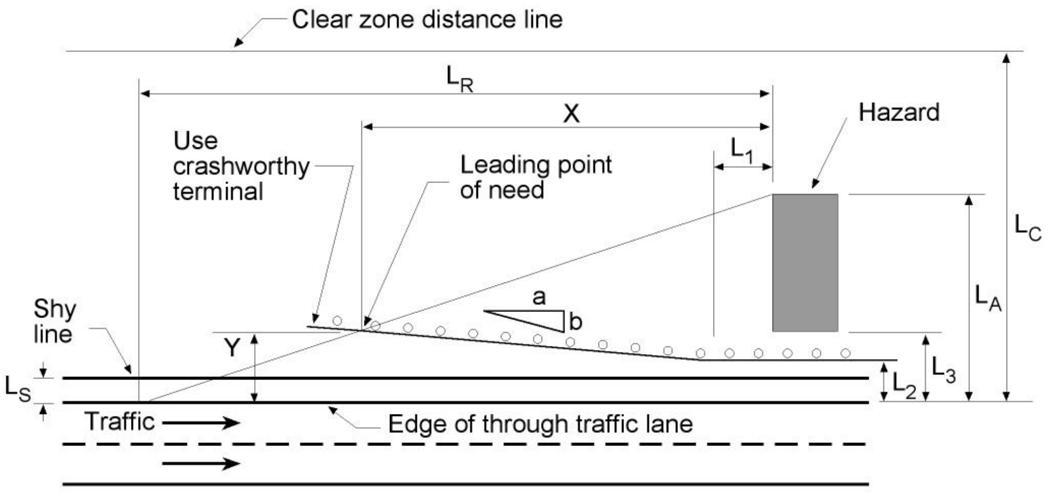
b/a = flare rate (Table 6.5)

L_A = lateral extent of the area of concern

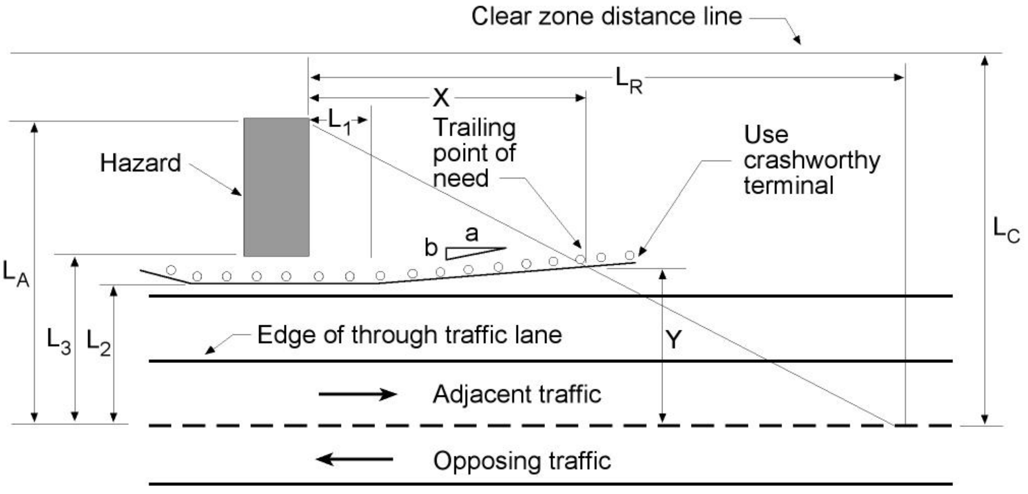
Y = lateral distance from edge of traffic lane to point of need.

These parameters are illustrated in Figure 6.23. The barrier length is a function of the distance that it is located from the edge of the driving lane and can most readily be obtained geometrically by drawing the length of need chord from the edge of the running lane at distance L_R from the hazard to the rearmost point of the hazard. The barrier should cross this chord as shown in Figure 6.23 (a) and (b).

Figure 6.23: Run-out length method of determining length of need



(a) Establishing leading point of need



(b) Establishing trailing point of need

Notes:

L_R *is the run-out length for the barrier.*

L_A *is the lateral extent of the hazard (edge of traffic lane to rear of hazard).*

L_1 *is the tangent length of the barrier upstream from the area of concern.*

L_2 *is the barrier's lateral distance from the edge of the traffic lane.*

L_3 *denotes the distance from the edge of the traffic lane to the nearest point on the hazard.*

L_C *is the clear zone distance.*

It should be noted that:

- The distance between the edge of the traffic lane and barrier affects the length of need; placing a flexible or semi-rigid barrier further from the road can result in a shorter barrier and lower installation and maintenance costs associated with shielding hazards. However, designers should refer to Section 6.3.4 for discussion on lateral location issues.
- The influence of roadside batter slopes on the design may be considered by completing the layout procedure on a scale plan, highlighting the hazard and showing the contour lines.
- L_A is the distance from the edge of the running lane to the far side of the fixed object, to the clear zone distance line (L_C) line, or to a point beyond the clear zone to shield a hazardous fixed object or feature that extends beyond the clear zone. Depending on site characteristics the designer may choose to shield only that portion of a hazard that lies within the clear zone by setting L_A equal to L_C.
- L_1 is chosen by the designer. For the situation where a semi-rigid railing is connected to a rigid barrier, it is suggested (AASHTO 2006) that the tangent length should be at least as long as the transition section. This measure reduces the possibility of pocketing at the transition and increases the likelihood of smooth redirection if the barrier is struck immediately adjacent to the rigid barrier.

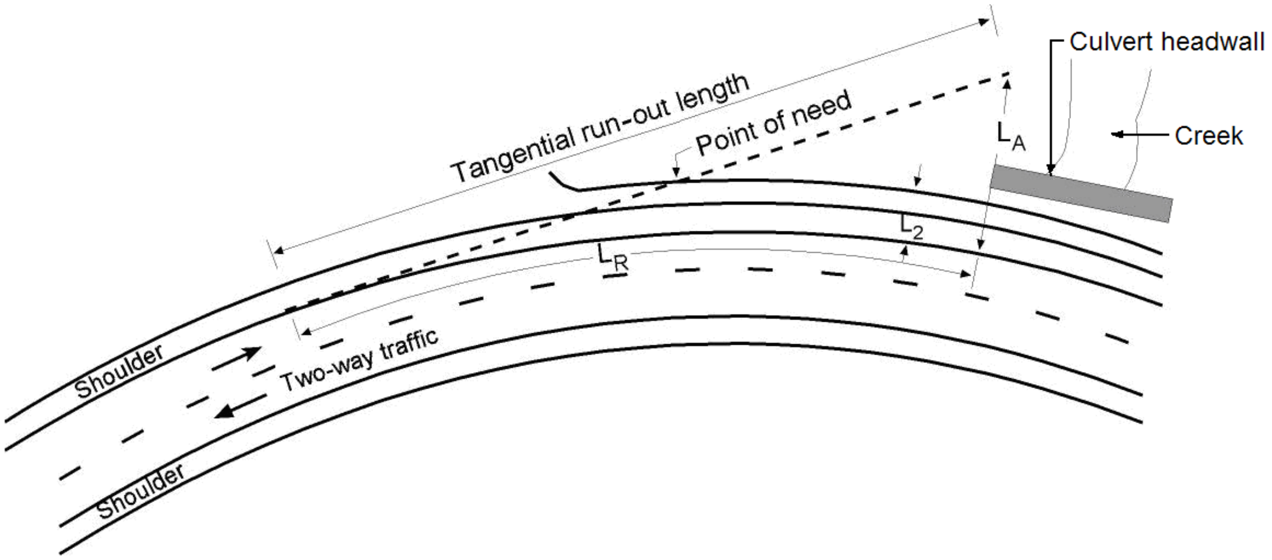
The result of these calculations is the required length of need of an approach barrier for traffic in the lane immediately next to the barrier. For opposing traffic, an approach longitudinal barrier length of need is calculated in the same manner. In this case, all lateral dimensions are measured from the edge of the opposing traffic lane that is nearest to the hazard (Figure 6.23(b)).

Curved sections of road

The length of need formula is applicable only to straight sections of road. For barrier designs on the outside of horizontal curves, it is assumed that a vehicle's exit path from the road will follow a tangential run-out path if the area outside the roadway is flat and traversable. Therefore, rather than using the theoretical L_R distance to determine the barrier length of need, a line from the outside edge of the hazard (or the clear zone for a continuous non-traversable feature) to a tangent point on the curve should be used to determine the appropriate length of need for the barrier (Figure 6.24).

The barrier length then becomes a function of the distance it is located from the edge of the driving lane and can most readily be obtained graphically by scaling (AASHTO 2006). Depending on the radius of the curve, a flare may not be required on the barrier but a properly designed and installed, crashworthy end treatment will be required.

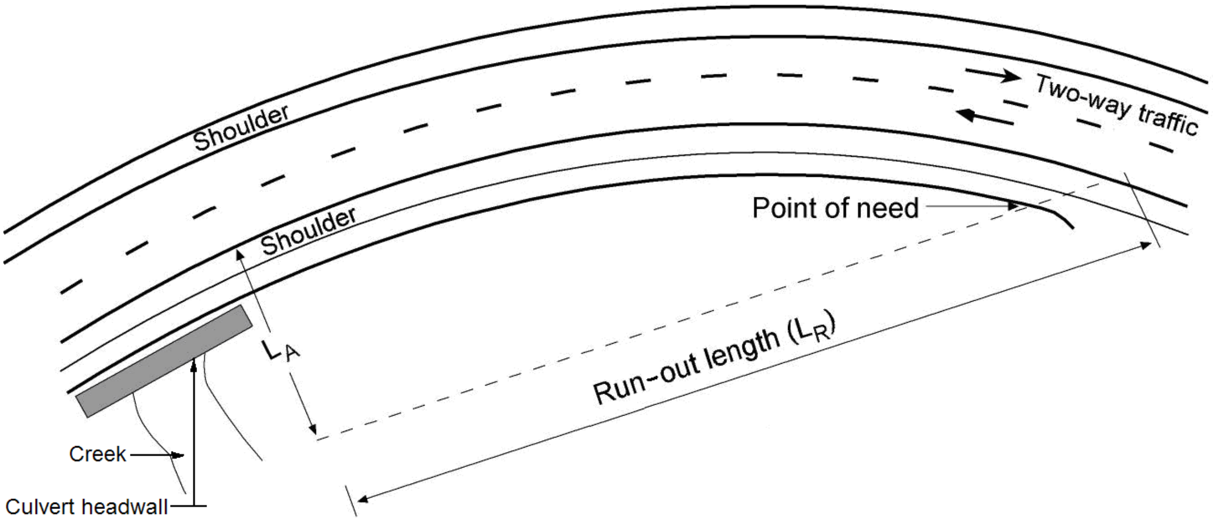
Figure 6.24: Length of need on outside of curve using run-out length method



Note: In the case depicted, both the culvert headwall and creek are hazards.

For barrier designs on the inside of curves the length of need is based on the length of run-out (L_R) projected from the edge of the traffic lane to the rear of the hazard (Figure 6.25). This is based on the premise that a vehicle leaving the road in advance or at the departure point will be able to stop before reaching the hazard or pass to the rear of it. The various possible vehicle trajectories beyond this departure point will be shielded from the hazard.

Figure 6.25: Length of need on inside of curve using run-out length method



Note: In the case depicted, both the culvert headwall and creek are hazards.

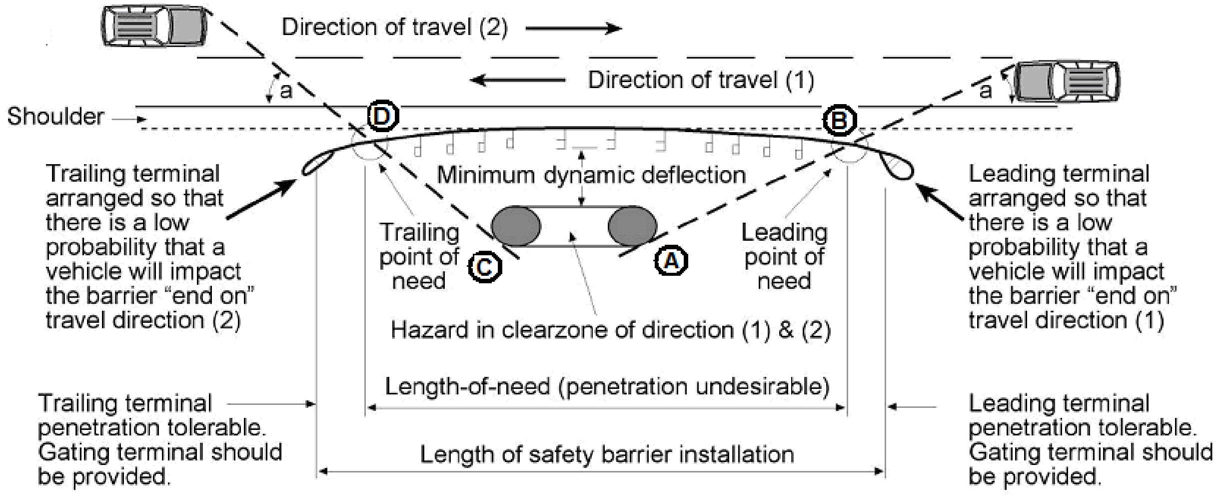
Angle of departure method

The angle of departure method is preferred by some road authorities as it determines the length of barrier required from angles at which vehicles are assumed to leave the road.

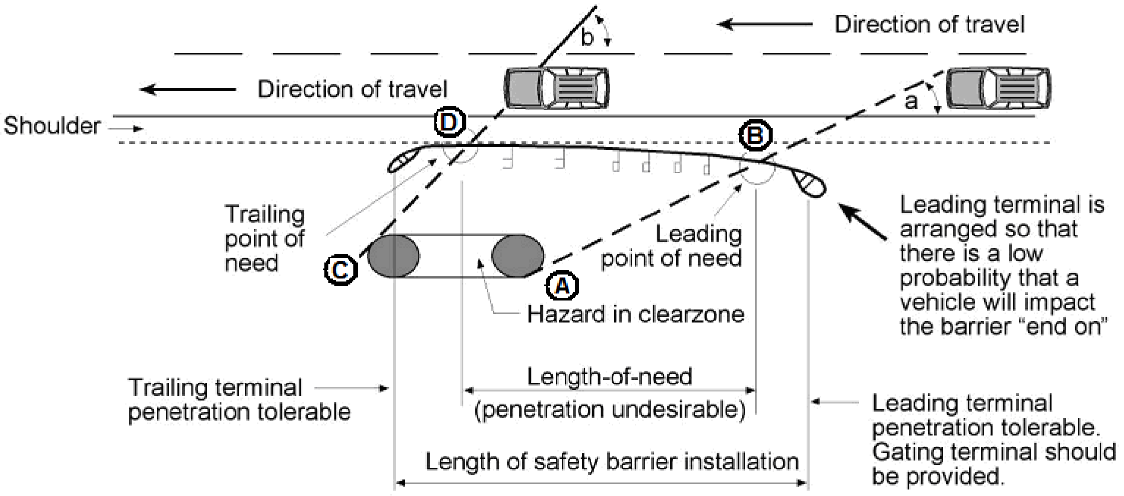
Straight sections of road

The angle of departure of vehicles leaving the road varies over a range of values. In this method vehicle trajectories are plotted based on angles at which most vehicles are likely to depart from the traffic lane, in order to establish the barrier points of need and the length of barrier required. This method is illustrated in Figure 6.26. The angle of departure is related to the posted speed limit and values are shown in Table 6.10.

Figure 6.26: Angle of departure method of determining length of need



(a) Two-lane two-way road



(b) Wide multi-lane carriageway or one-way carriageway

Source: Based on RTA (1996).

Table 6.10: Angles of departure from the road

Signposted speed limit (km/h)	15th percentile angle (1:X) use as leading angle (*'a'*)	85th percentile angle (1:X) use as trailing angle *('b')*
60/70	5.7° (1:10)	22° (1:2.5)
80/90	3.8° (1:15)	22° (1:2.5)
100/110	2.9° (1:20)	22° (1:2.5)

Note: For operating speeds less than 60 km/h use the values for 60/70 km/h.

Source: RTA (1996).

The method to establish points of need for a two-direction carriageway (Figure 6.26(a)) is:

1. Identify the first possible point of contact with the hazard for direction 1 (the lane adjacent to the barrier) (Point A).
2. Using the impact angles from Table 6.10, project a line at the leading impact angle until it intersects the offset line of the barrier (Point B).
3. Record this as the leading point of need.
4. Identify the first possible point of contact with the hazard for direction 2 (the opposite lane) (Point C).
5. Using the impact angles from Table 6.10, project a line at the leading impact angle until it intersects the offset line of the barrier (Point D). Record this as the trailing point of need.

From these points establish the longitudinal position and length of the barrier installation.

The method to establish points of need for a single-direction carriageway (Figure 6.26 (b)) is:

1. Identify the first possible point of contact with the hazard (Point A).
2. Using the impact angles from Table 6.10, project a line at the leading impact angle until it intersects the offset line of the barrier (Point B).
3. Record this as the leading point of need.
4. Identify the last possible point of contact with the hazard (Point C).
5. Using the impact angles from Table 6.10, project a line at the trailing impact angle until it intersects the offset line of the barrier (Point D). Record this as the trailing point of need.

If the hazard is located on a median and is in the area of interest (i.e. clear zone distance) for the opposing direction of traffic, repeat the process for the opposing direction of traffic.

Curved sections of road

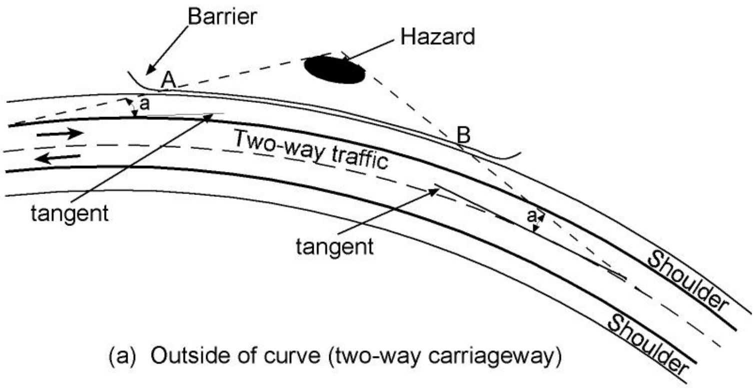
When determining the leading point of need for a road safety barrier, the angle of departure of an errant vehicle should be taken from the outer edge of the travel lane in all cases. Working back from the obstacle will give the same result if the lane/road alignment is straight, but when the alignment is curved, the leading and trailing angles of departure should be determined from a tangent on the outside of the edge of the travel lane.

For a curve, the leading angle of departure from Table 6.10 (2.9° for speeds equal to or greater than 100 km/h) is taken off a tangent to determine where the initial point of need lies when this angle meets with the back of a hazard that is located within the clear zone. The trailing angle of departure at 22° is then taken from a tangent in front of the hazard to determine the final point of need for a one-way road. Figure 6.27 (a) to (d) illustrates the situations for hazards on the outside and inside of a curve, and for two-way and one-way carriageways.

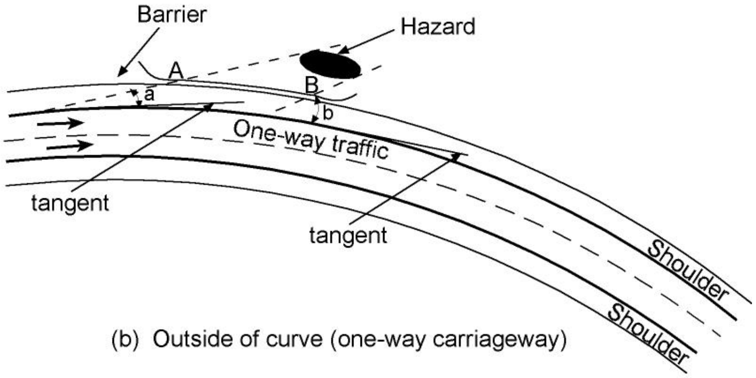
In determining the length of need for a road safety barrier, there is a range of angles of departure that are considered between the leading angle of 2.9° (at 100 km/h) and the trailing angle of 22° (for all speeds). These are general limits and when applied in cases where the leading angle from Table 6.10 does not meet with the hazard, a departure angle that is somewhere between the leading and trailing limits must be considered.

On the inside of a horizontal curve, a slightly different procedure is required if the leading angle of departure does not meet with the back of the hazard (i.e. the line passes through or in front of the hazard), and as a consequence the initial point of need for the road safety barrier does not relate to the rear of the hazard. However, the leading and trailing angles cover a range and an angle within these limits can be used as a leading angle for establishing the initial point of need. Therefore, in these situations a chord to the curve should be drawn across the back of the hazard, square to the centre of the curve. This process is illustrated in Figure 6.28 (a) and (b) for two-way and one-way carriageways. The chord should be extended to intersect with the edge of travel lanes at point A and B. Point A is where the leading angle of departure begins for traffic in the lane adjacent to the hazard, and B is the corresponding point for the opposing traffic. The leading angle of departure is the angle between the chord and the tangent to the curve at A. It can be calculated and will be somewhere in the range of 2.9° to 22° for a speed limit of 100 km/h or greater.

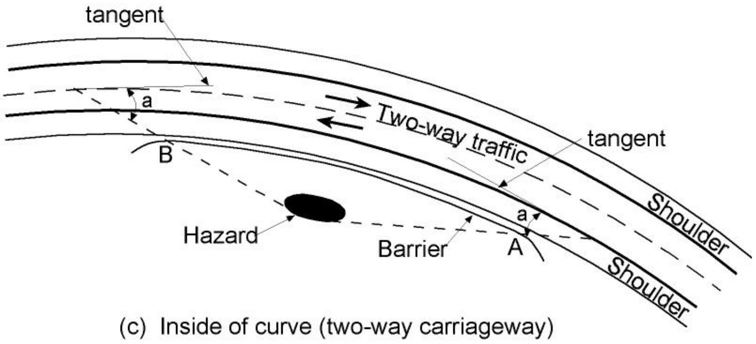
Figure 6.27: Angle of departure method on curves where leading angle meets the rear of hazard



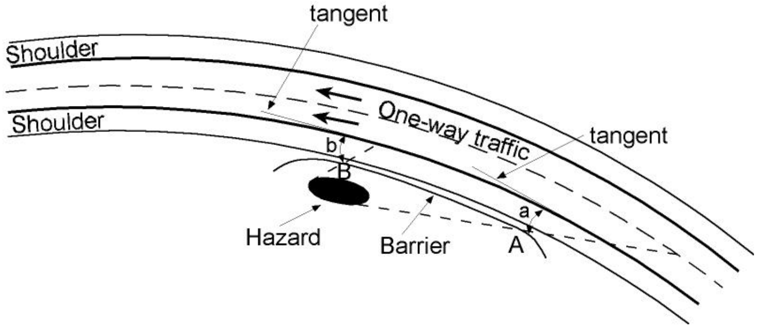
(a) Outside of curve (two-way carriageway)



(b) Outside of curve (one-way carriageway)



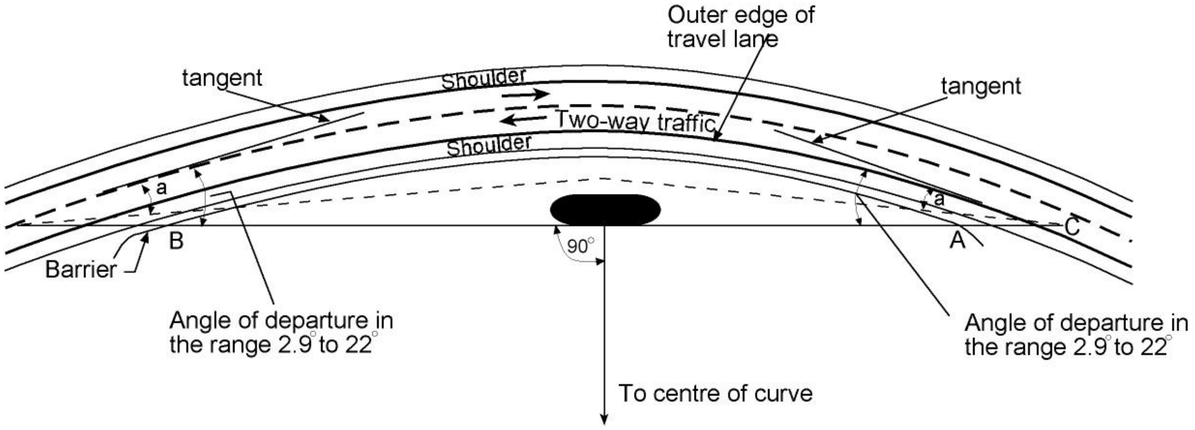
(c) Inside of curve (two-way carriageway)



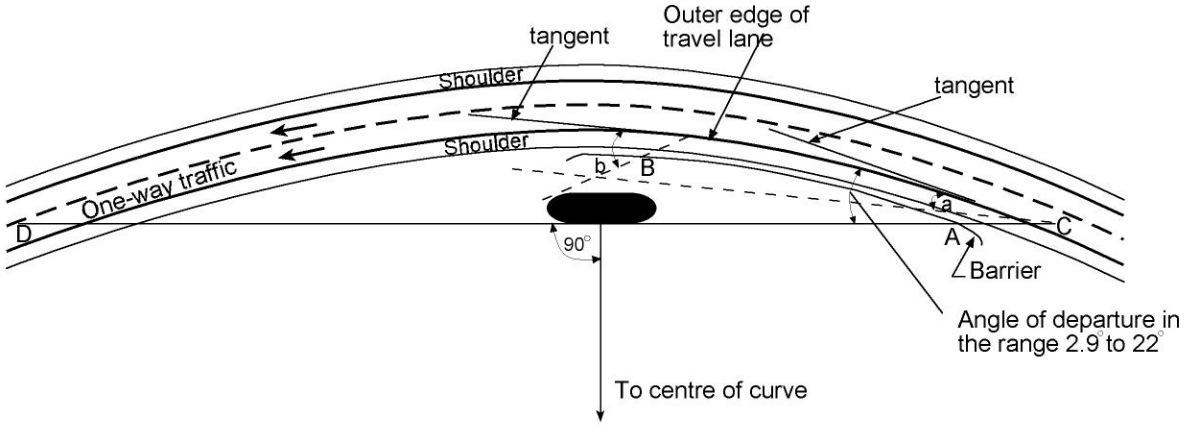
(d) Inside of curve (one-way carriageway)

Note: A-B is the length of need.

Figure 6.28: Angle of departure method where leading angle does not meet the rear of hazard



(a) Two-way carriageway



(b) One-way carriageway

Notes:

A-B is the length of need.

C-D is the chord across the rear of the hazard.

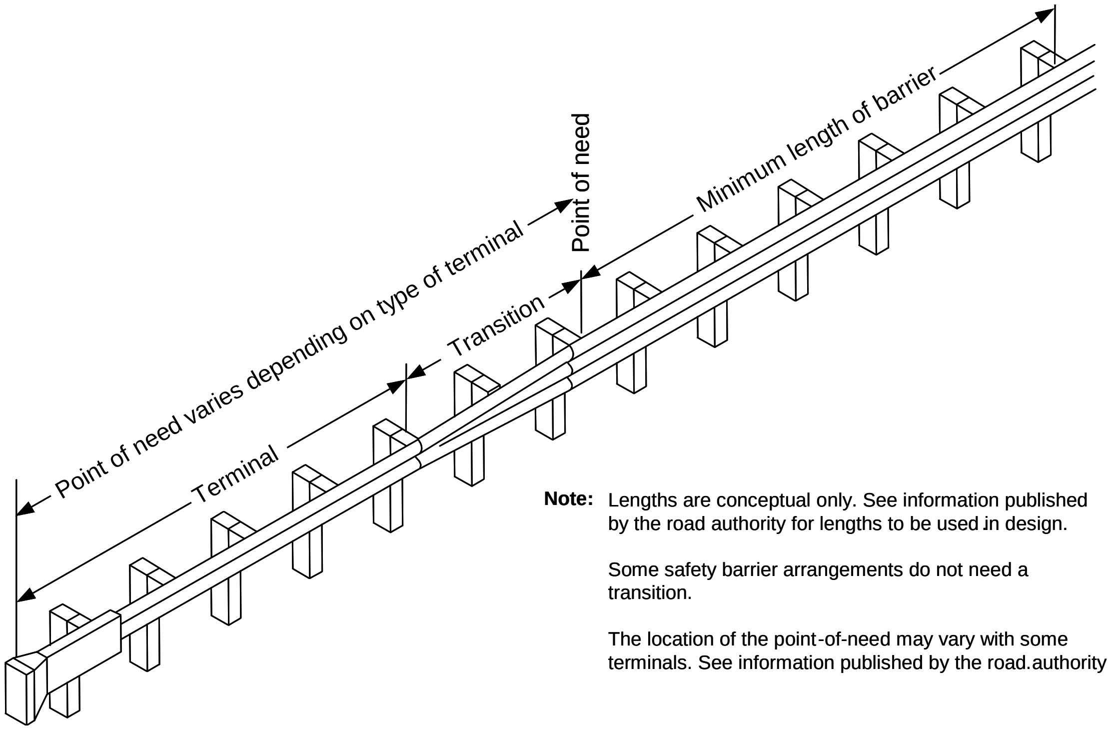
6.3.20 Step B12 – Check that the Minimum Length of Barrier is Provided

In order to perform satisfactorily, barriers must have sufficient length to enable the strength to be developed through the system and into the foundations and/or anchorages as impact occurs. Designers should therefore check that the distance between the leading and trailing points of need is greater than the minimum length of barrier for the chosen barrier category. The lengths to be considered in the design of road safety barriers are the:

- terminal length
- transition length
- minimum length of barrier
- development length.

These lengths are shown conceptually for anchored and unanchored barrier systems in Figure 6.29 and Figure 6.30 respectively. The development length applies to unanchored road safety barriers and is the length in advance of the point of need that is necessary to provide sufficient mass for the barrier within the length of need to perform in accordance with its design parameters.

Figure 6.29: Road safety barrier lengths – anchored systems



Note: Lengths are conceptual only. See information published by the road authority for lengths to be used in design.

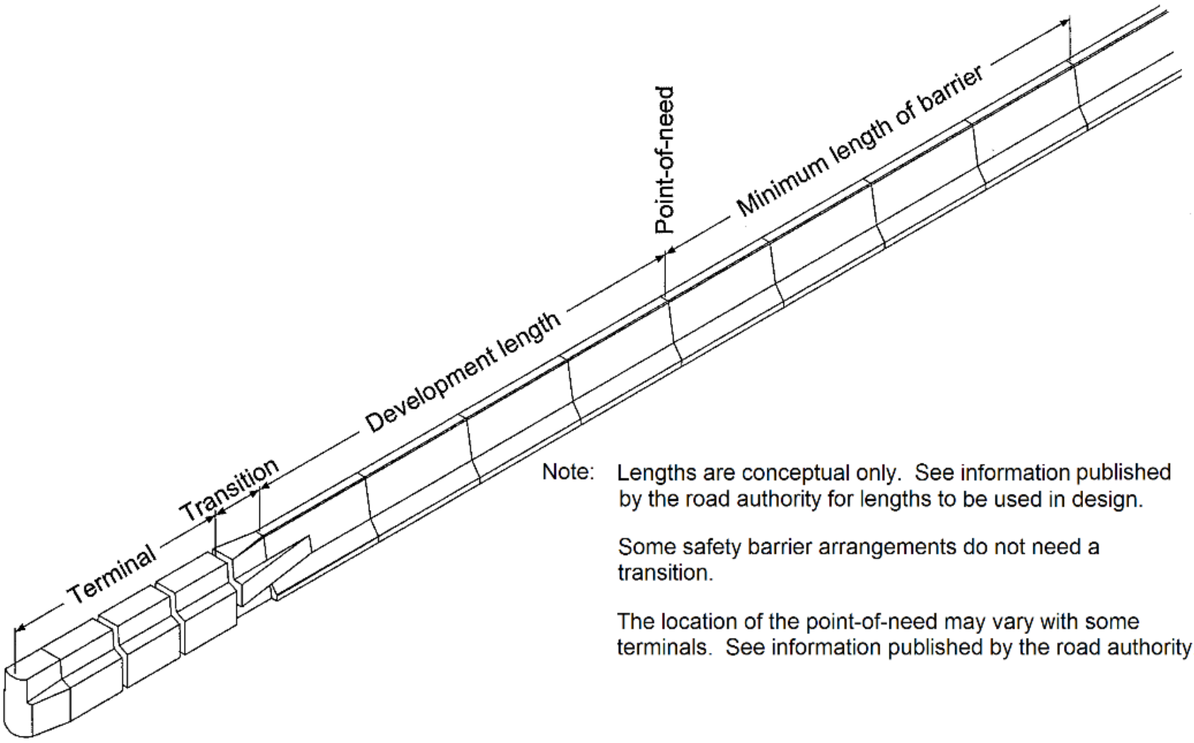
Some safety barrier arrangements do not need a transition.

The location of the point-of-need may vary with some terminals. See information published by the road authority.

Note: Point of need is defined in Table A 3 of Appendix A.

Source: Based on RTA (2008).

Figure 6.30: Road safety barrier lengths – unanchored systems



Note: Lengths are conceptual only. See information published by the road authority for lengths to be used in design.

Some safety barrier arrangements do not need a transition.

The location of the point-of-need may vary with some terminals. See information published by the road authority.

Notes:
Point of need is defined in Table A 3 of Appendix A.
For some barriers designers may consider whether the development length should contribute to minimum length of barrier.
Source: RTA (2008).

6.3.21 Step B13 – Check Sight Distance

Barriers on horizontal curves can impede stopping sight distance. Barriers located close to intersections can impede the safe intersection sight distance and minimum gap sight distance available to drivers attempting to select a safe gap in traffic on the major road. This issue applies to barriers located on the verge and barriers located in medians.

For sight distance requirements in mid-block situations including horizontal curves, designers are referred to Section 5 of the *Guide to Road Design – Part 3: Geometric Design* (Austroads 2009b).

For sight distance requirements associated with intersections and interchanges designers are referred to the:

- Guide to Road Design – Part 4A: Unsignalised and Signalised Intersections (Austroads 2009d)
- Guide to Road Design – Part 4B: Roundabouts (Austroads 2009e)
- Guide to Road Design – Part 4C: Interchanges (Austroads 2009f).

6.3.22 Step B14 – Choose Terminal Treatments

General

Once the barrier has been located longitudinally (points of need) and laterally to accommodate dynamic deflection, suitable leading and trailing terminal treatments must be selected for use. Crashworthy terminals are used on safety barriers that:

- terminate within a clear zone
- are located in an area where they are likely to be hit head-on by an errant vehicle.

Terminal treatments and crash cushions or impact attenuators are used to terminate a road safety barrier. These devices are specifically designed to ensure that the ends of road safety barriers provide safe conditions for occupants of vehicles that may impact this area of a road safety barrier. They must be used on all rigid and semi-rigid barrier systems. Flexible barriers have an end anchorage and when impacted head-on the posts and cables collapse as the vehicle decelerates.

Key performance aspects (AS/NZS 3845 – 1999) are that barrier terminals should:

- Where necessary, incorporate an anchor to the road safety barrier system to enable the full tensile strength of the system to be developed during impacts with the barrier at locations away from the terminal.
- Not cause an impacting vehicle to roll, vault or yaw in an inappropriate manner (applies to leading and trailing terminals).
- Not spear the impacting vehicle or cause undue problems with debris.
- Should perform acceptably when impacted from either direction, except when erected on a single direction carriageway where there is a low probability of a vehicle impacting the terminal from the reverse direction.
- Should not distinguish between a temporary or permanent situation. The only exception may be an allowance for the reduction of impact forces where the site is effectively managed (i.e. if the maximum traffic speed is controlled, then a lower performance end terminal treatment may be used than would otherwise be required).
- Be tested in accordance with AS/NZS 3845 – 1999 and as the tests are undertaken in a controlled environment actual site conditions need to be considered when selecting an end terminal treatment.

Where a road safety barrier is located some distance from the edge of the road it may be possible to flare the barrier and terminate it beyond the clear zone. In such cases, because a significant percentage of errant vehicles may travel beyond the clear zone, it is preferable that a crashworthy end treatment is provided. A non-crashworthy end treatment should only be considered where a detailed assessment concludes that the likelihood of an end-on impact with the barrier is very low (i.e. negligible).

A crash involving a vehicle impacting an untreated or inappropriately treated end of a road safety barrier can have serious consequences for the occupants because the:

- vehicle is stopped abruptly
- barrier may penetrate into the occupant space of the vehicle
- vehicle may be launched and roll over.

It is therefore imperative that terminal treatments are appropriate for the type of barrier and installed in accordance with the manufacturer’s specifications and relevant road authority guidelines. The type of terminal treatment used depends on the type of barrier and its performance level. Some treatments function only to provide a safe terminal for the barrier, while others also function as an anchor for the system.

A barrier terminal treatment may fulfill its function by:

- permitting controlled penetration by the vehicle into an area behind the device
- decelerating a vehicle to a safe stop within a relatively short distance
- containing and redirecting the vehicle
- a combination of the above.

Road safety barrier terminals are generally classified as either a gating/non-gating terminal or as a crash cushion/impact attenuator (refer to page 118).

Selection factors for terminal treatments

The selection of the most appropriate crashworthy terminal treatment for a barrier should take into account the:

- need for gating or non-gating characteristics
- need for redirective or non-redirective characteristics
- speed environment
- space available for installation and deformation of the terminal
- need for a run-out area behind the barrier
- width required for accommodation and deformation of the terminal
- capacity to absorb nuisance crashes
- compatibility with barrier type
- cost and maintenance factors.

The gating and non-gating characteristics are discussed on page 118 and the redirective and directive characteristics of barriers are discussed on page 122, whereas the other selection factors are summarised in Table 6.11.

For crash cushions or impact attenuators the following aspects should also be considered:

- Type – redirective or non-redirective.
- Classification – if a re-directive cushion is required then it needs to be specified if it is to be gating or non-gating.
- Performance level – some cushions have achieved multiple test levels and for some products the system owner can provide configurations for different design speeds rather than various test levels.
- Configuration – crash cushions may be available in different configurations including width, anchoring in terms of rigid backstops, different colours of nose cones and only certain configurations may be acceptable to the relevant road agency. Side panel/rail laps may vary depending on whether the adjacent passing traffic is one-way or two-way. For some systems the side panels are aligned to accommodate the direction of travel.
- Transitions – there may be a number of options available depending on the direction of impact (uni-directional or bi-directional) and the hazard or barrier system to which the cushion is to be connected.
- Foundation options – some cushions have a range of foundation options and only certain options may be acceptable to the relevant road agency or applicable to the specific site in which the cushion is to be installed.
- Site conditions – there are design limitations (e.g. maximum crossfall) which may limit the use of certain devices.

A number of terminal treatments that have been used in the past are no longer suitable for use because they enable the barrier to penetrate (or spear) the cabin space of light vehicles and/or cause vehicles to vault or roll. These terminal treatments include:

- splayed ends (fishtail ends) on W-beam barrier
- sloped (turned down into the ground) ends on semi-rigid or rigid barrier (although a sloped concrete terminal treatment may be suitable where speeds are low (e.g. 60 km/h or less) and space is limited by right-of-way constraints or the presence of other features preclude the use of one of the tested terminal treatments)
- a narrow double bull-nose terminal treatment on back-to-back W-beam
- break away cable terminals (non-slotted).

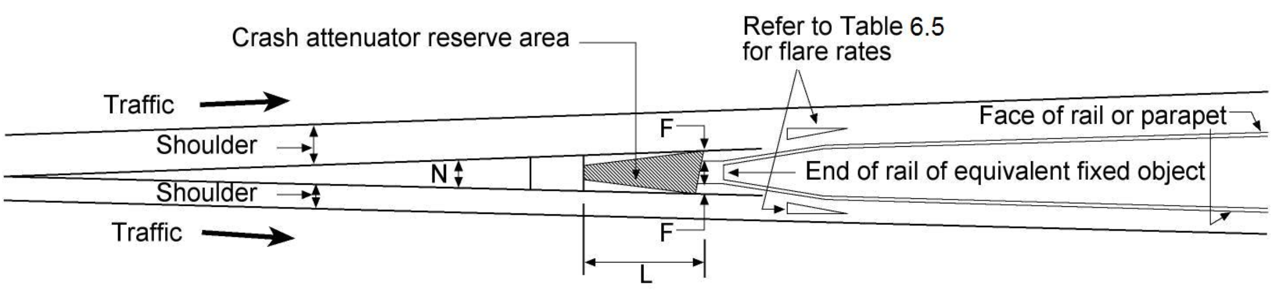
Table 6.11: Selection factors for terminal treatments

Factor	Considerations
Gating and non-gating characteristics	Refer to discussion under Gating and non-gating terminals
Redirective and non-redirective characteristics	Refer to discussion under Crash cushions and impact attenuators.
Speed environment	The terminal should be suitable for the speed environment at the location; terminals may have been tested for different speeds. Particular terminals and different configurations of the same crash attenuator will be suitable for particular speed environments. The operating speed should usually be taken to represent the speed environment. Where the operating speed is not known the speed limit + 10 km/h may be used provided that the speed zone exists some distance upstream of the installation. The length of some crash attenuators can be varied depending on the speed environment and likely maximum impact speed. Manufacturers' advice should be sought.

Factor	Considerations
Space availability	The installation should comply with all of the manufacturers' recommendations with respect to space. The space available for the attenuator or end treatment will also influence the type of terminal to be installed, for example: • some crash attenuators are more suited for use in narrow medians while others are suitable to shield wider hazards • some crash attenuators and end treatments such as the MELT (Figure 6.31) may require a large run-out area free of hazards for gating of the end, while others may require space to accommodate displacement of the attenuator clear of traffic. Consideration may be given to selecting a physically smaller system on the basis that a smaller size will reduce the number of crashes, especially nuisance crashes, thereby reducing the maintenance that must be undertaken following an incident. Space requirements of terminals should be allowed for during all stages of road design and construction (e.g. preliminary design for new works or rehabilitation of existing roads) to ensure compatibility between the final design and the terminal that is to be installed. Figure 6.32 is a guide, for planning purposes only, to the area that should be made available for crash attenuator installation.
Susceptibility to nuisance crashes	Terminals are susceptible to nuisance crashes. The system should be capable of performing satisfactorily following a number of minor crashes without requiring repair. It may be the case that a non-gating system would perform better than a gating system in this respect.
Compatibility to road safety barrier type	The terminal should be suitable for use with the proposed road safety barrier type. Manufacturers' specifications should therefore be consulted. In some instances a transition section will be required to ensure adequate stiffness is provided at the connection between the terminal and the road safety barrier. This is required to minimise vehicle snagging and pocketing of the road safety barrier, and to limit the change in deflection occurring between the road safety barrier and the end treatment.
Cost and maintenance factors	The whole of life cost should be taken into account when selecting a terminal including: • capital costs • maintenance costs • risks associated with maintenance repair times. Site preparation costs to accommodate some systems can also be significant. Crash attenuators are relatively costly to install and to repair after impact, so they are generally used only where it is likely that errant vehicles will hit a hazard with severe consequences, and either: • it would be very difficult or costly to remove or relocate the hazard, make it frangible, or realign the traffic path away from the hazard • there is insufficient room for a normal road safety barrier and its terminals, or normal road safety barrier ends would form unacceptable hazards (e.g. in some narrow medians). At locations where frequent hits are expected, life cycle costs for repairing or replacing an attenuator system may be a significant factor in the selection process. The repair and replacement time for an attenuator system following an impact is also an important consideration as this can cause significant losses to road users through delays. The direct costs associated with worker safety and traffic management also need to be considered.

Figure 6.31: W-beam with gating terminal (e.g. MELT) and trailing terminal

Figure 6.32: Space required for crash attenuators in gore areas



Design speed on main carriageway	Dimensions for crash attenuators, reserve area (metres)								
	Minimum						Preferred		
	Restricted conditions			Unrestricted conditions					
	N	L	F	N	L	F	N	L	F
50	2	2.5	0.5	2.5	3.5	1	3.5	5	1.5
80	2	5	0.5	2.5	7.5	1	3.5	10	1.5
110	2	8.5	0.5	2.5	13.5	1	3.5	17	1.5
130	2	11	0.5	2.5	17	1	3.5	21	1.5

Notes:

The information provided in this table is generic and should therefore be used only for planning purposes. Detailed product information should be used for design purposes.

Although the figure depicts a gore location, the same recommendations will generally apply to other types of fixed objects that require shielding (AASHTO 2006).

The unrestricted conditions represent the minimum dimensions for all locations except for those sites where it can be demonstrated that the increased costs for obtaining these dimensions (as opposed to those for restricted conditions) will be unreasonable. The preferred conditions dimensions should be considered optimum.

Source: AASHTO (2006).

Gating and non-gating terminals

Gating terminals and non-gating terminals can be either a public domain product (e.g. a MELT treatment) or a proprietary product (e.g. extruding head terminal).

Gating terminal systems are designed to allow a vehicle impacting the nose, or the side of the terminal at an angle near the nose, to pass through the terminal and behind the barrier. They may break away, hinge or pivot when impacted. Gating terminals are therefore not suitable for use where there is a high potential that an errant vehicle may travel through the treatment and into a hazard or into opposing traffic lanes (e.g. in narrow medians). A gating terminal is considered to have functioned properly if the vehicle remains stable during and after impact and is kept away from the hard point of the road safety barrier system.

Gating treatments for semi-rigid road safety barriers comprise either a weakened section of W-beam that hinges or moves out of the way on impact (e.g. MELT terminal), or devices that cause the beam to deform or absorb the kinetic energy of the vehicle. Crash cushions and impact attenuators (see page 120), designed to be used as a terminal for concrete road safety barriers or to shield other fixed objects may also be designed to ‘gate’. For gating end treatments, the length of need usually starts about one panel of rail from the impact head of the unit, but this can vary depending on the specific terminal used.

Vehicles that pass through a gating treatment are directed into the area behind the end treatment (i.e. on the side of the road safety barrier opposite the travelled lane). Figure 6.33 illustrates both a flared gating terminal and a parallel gating terminal and the required area behind the barrier. It is necessary to ensure that this run-out area should:

- contain no fixed hazards (e.g. poles and trees)
- be traversable, with a lateral slope of 4:1 or flatter
- extend parallel to the barrier/terminal at least for a distance of 18 m beyond the point of need for the barrier/terminal.
- be at least 6 m wide.

The 18 m long hazard-free area (measured from the point of need of any gating treatment) is based on the 22.5 m long hazard-free area (measured from the start of a modified eccentric loader treatment, (i.e. MELT as shown in Figure F11 of AS/NZS 3845:1999). The 18 m is derived from 22.5 m minus the length from the start of a MELT to the point of need at the third post (i.e. 22.5 minus the bullnose length minus 2 post spacings = 22.5 – 0.5 – 2 x 2.0 = 18 m).

As end treatments are designed and tested on flat and level terrain with a vehicle impacting at normal height, it is imperative that these conditions be replicated in practice. Failure to do so may result in the device failing to perform as intended. Terminals must therefore be placed on a relatively flat surface (10:1 maximum slope) and the path between the road and the attenuator must be clear of any irregularities or obstructions, such as excessive slopes or kerbs. These features can cause a vehicle to become airborne and ride over the road safety barrier or roll over on impact. Maximum crossfalls are recommended for various types of proprietary terminal systems.

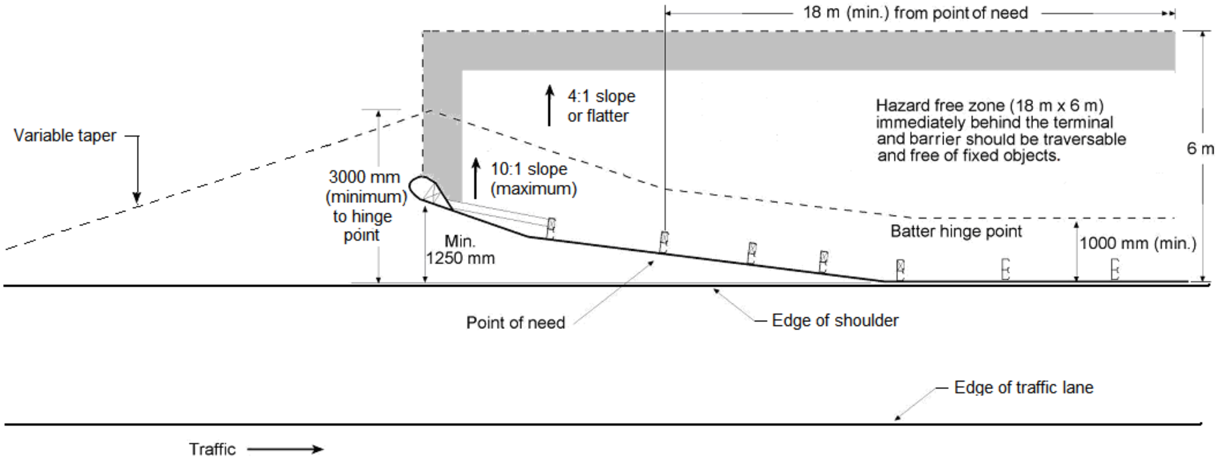
The 18 m x 6 m dimensions are minimum figures and may not be sufficient for all collisions. If a run-out area cannot be provided or would be smaller than these dimensions, a non-gating terminal should be used.

For flexible and semi-rigid road safety barrier types, terminal treatments must be properly anchored so that the design operational requirements are achieved in practice. Any re-directive capability required by the design will only be achieved by the end treatment developing the same full tensile strength as the road safety barrier upon impact.

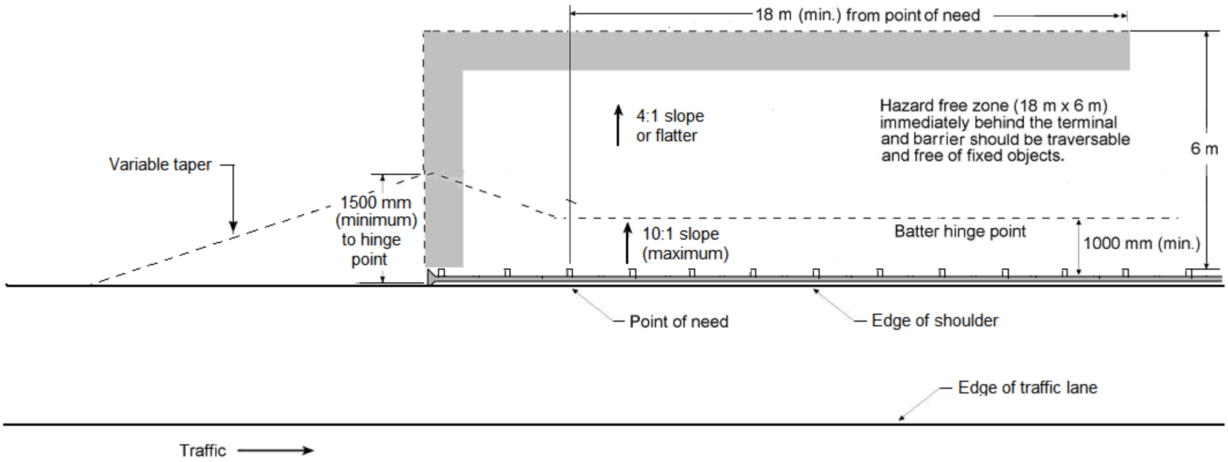
Non-gating terminals do not allow vehicles to pass through the leading section of the terminal as they are designed to contain an impacting vehicle and redirect it along the length of the terminal towards the barrier. Most non-gating terminal treatments are crash attenuators that do not allow a colliding vehicle to pass behind the terminal. On colliding with the end of the terminal, the vehicle will be redirected away from the barrier or be arrested by the barrier. The point of need for a non-gating system is at the nose. A barrier with a non-gating terminal does not require a run-out area.

Wire rope safety barrier (WRSB) terminal treatments should be provided in accordance with the manufacturer's specification. The end anchors are frangible and designed to ensure that when impacted the wire ropes are restrained and not a hazard to adjacent traffic. An errant vehicle running into the end of a WRSB straddles the cables and may be arrested by them as the vehicle progressively flattens posts and comes to rest.

Figure 6.33: Run-out area for gating terminals



(a) Flared barrier



(b) Parallel barrier

Notes:

The 18 m long hazard-free area (measured from the point of need of any gating treatment) is based on the 22.5 m long hazard-free area (measured from the start of a modified eccentric loader treatment, (i.e. MELT as shown in Figure F11 of AS/NZS 3845:1999). The 18 m is derived from 22.5 minus the length from the start of a MELT to the point of need at the third post (i.e. 22.5 minus bullnose length minus two post spacings = 22.5 – 0.5 – 2 x 2.0 = 18 m).

Designers should note that the dimensions shown are a minimum requirement and there are benefits in providing a longer and wider run-out area.

In constrained circumstances it may not be possible to provide the run-out area. In these situations, designers should assess the risk involved with the use of a gating end treatment and no suitable run-out area versus other options such as the use of a non-gating end treatment.

This figure indicates grading requirements for a parabolic flared end treatment and for a parallel end treatment.

Crash cushions and impact attenuators

In some situations a crash cushion will be the most appropriate device. Crash cushions and impact attenuators are protective devices that prevent errant vehicles from impacting fixed hazards. This is achieved by absorbing energy at a controlled rate to decelerate a vehicle in a short distance to a safe stop before impact with the hazard. Some crash cushions redirect the vehicle away from the hazard when impacted at an angle.

Crash cushions are suited to protect larger hazards which cannot be removed, relocated or protected by a conventional safety barrier. They are proprietary products and therefore the dimensions and installation requirements should be sourced from information published by the manufacturer and the relevant road authority should be consulted regarding the use of the device.

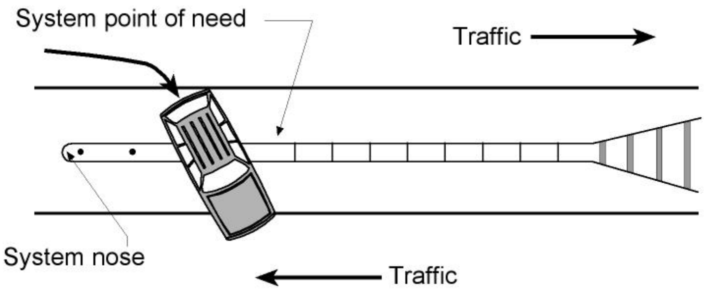
The principles on which crash cushions and impact attenuators operate are described in Commentary 13.

Crash cushions and impact attenuators can be classified as:

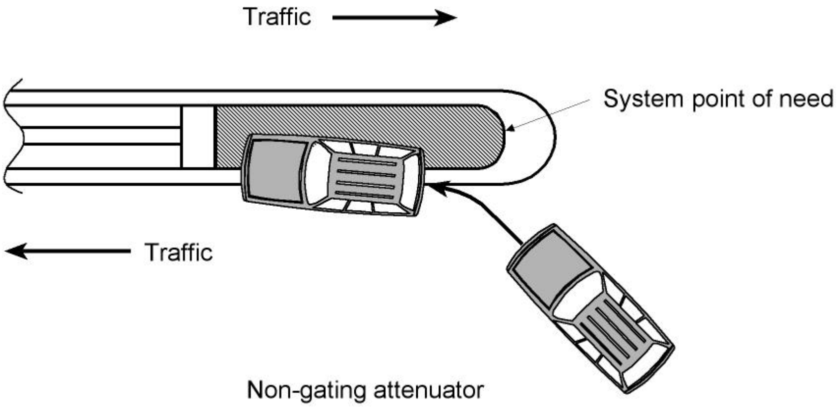
- gating or non-gating, depending on their behaviour when impacted on the side near the leading end of the barrier
- redirective or non-redirective depending on their ability to redirect impacting traffic away from the hazard.

Figure 6.34 illustrates the behaviour of gating and non-gating systems while Figure 6.35 illustrates the behaviour of redirective and non-redirective systems.

Figure 6.34: Gating and non-gating systems

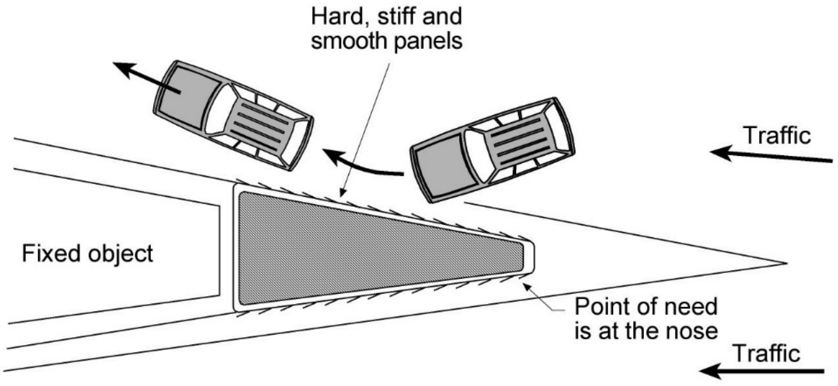


Gating attenuator

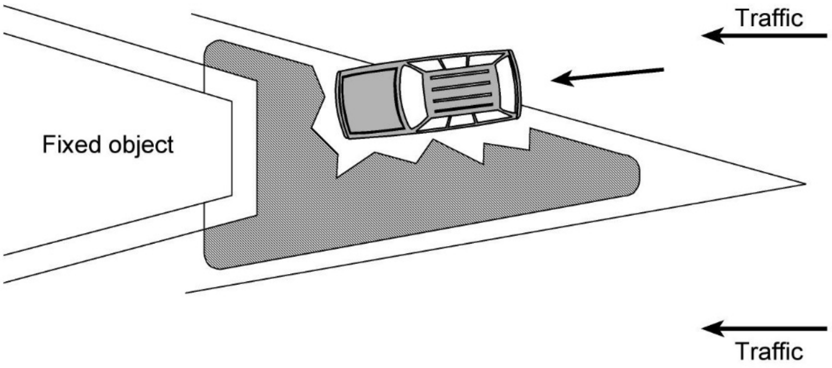


Non-gating attenuator

Figure 6.35: Redirective and non-redirective systems



a) Redirective system



b) Non-redirective system

A gating/redirective crash attenuator can function well in both head-on and side-angle impacts. The kinetic energy of the vehicle is absorbed by crushable or plastically deformable materials, or by the use of hydraulic energy absorbers placed in front of an obstacle (AASHTO 2006). Most impact attenuators are based on this concept and need a rigid support to resist the vehicle impact force as the energy-absorbing material is deformed.

When impacted head-on, these impact attenuators have the energy-absorbing ability to slowly bring the vehicle to a safe stop. Angle impacts in the leading section cause the device to ‘gate’ and, when subjected to glancing or side angle impacts beyond the point of need, they redirect vehicles back into their originally intended direction of travel.

A non-redirective crash attenuator performs most effectively when hit head-on. These attenuators comprise barrels or containers, typically filled with variable masses of sand, and their performance is based on the transfer of momentum of a moving vehicle to an expendable mass of material located in the vehicle’s path. This is the only type of crash attenuator for which the design can be analytically determined. They are designed in accordance with the principle of conservation of momentum whereby the kinetic energy of the impacting vehicle is transferred to the mass of sand. These devices require no rigid back up or support.

In a crash, a non-redirective crash attenuator stops a vehicle in head-on impacts, and in side-angle impacts is unable to redirect the vehicle back into its intended direction. This limitation results in continued forward motion at a high speed, with the consequence that the vehicle penetrates the attenuator. The impacting vehicle continues in the same direction until it either is arrested by the device or impacts an object (e.g. near the rear end of the device, refer to Figure 6.35(b).

Crash attenuators should be orientated so that they face the most likely direction of impact which is particularly important where the approach is on a tight curve (a situation that may be encountered in construction zones).

Specific types of terminals

Gating and non-gating terminals may be public domain or proprietary products. Public domain terminals are described in AS/NZS 3845 – 1999 and commonly used examples are illustrated in Appendix J. The design of proprietary terminals may change over time due to product development and therefore designers should remain familiar with the products that are available (e.g. through relevant websites) and the specifications relating to the products and their use. Appendix J also provides some generic information on proprietary products.

6.3.23 Step B15 – Design the Transitions Between Barriers

General

Wherever it is necessary to change from one type of barrier to another, or to physically join them together (e.g. a bridge barrier to a road barrier), the interface must be designed to ensure that the overall system will perform safely when impacted by an errant design vehicle.

Interfaces are designed to provide a smooth, snag-free transition between different types of barriers where they meet, such as at bridge parapets. Inappropriate, incorrectly installed or missing interfaces present a hazard to vehicles impacting the barriers at or near the interface point (i.e. the end of the concrete or steel bridge barrier).

Different profiles of semi-rigid steel road safety barrier and different profiles of rigid barrier can all be interfaced with a properly designed continuous transition whereas interfaces between flexible barriers and more rigid systems can only be affected by overlapping the different systems. In the latter case the more flexible system must be placed in front of the more rigid section.

System interfaces that require an overlap should be designed on the basis that the terminating system will overlap in front of a system that is beginning, irrespective of the system type. The barriers should be separated by a clearance at least equivalent to the dynamic deflection of the terminating system.

For interface details designers should refer to manufacturer's specifications, standard drawings and guidelines on appropriate use of interfaces that are available from the relevant road authority. Transitions are described in detail in Appendix L.

Bridges

Road safety barriers for bridges, including the transitions between bridge barriers and road barriers, should be designed in accordance with AS 5100.1 – 2004.

The design procedure in AS 5100.1 – 2004 is focussed on bridge railings. However, the procedure could also be applied to sites on the approaches to bridges and at other (non-bridge) locations on roads where similar conditions exist. The procedure comprises:

- a selection method that leads to a recommendation for a low (TL2), regular (TL4) or medium (TL5) performance level barrier
- descriptive advice on the assessment of individual medium-risk to high-risk sites, using risk assessment and benefit-cost analysis to determine whether a higher performance level barrier should be provided.

The selection method takes into account factors for road type, downgrade, curvature, deck height and under-structure conditions, commercial vehicle percentage, and speed environment.

AS 5100.1 – 2004 also provides information on barriers for bicycle and pedestrian bridges and for some design elements for bicycle/pedestrian paths as they relate to bridges.

Bridge approaches

Transitions from approach barriers to bridge barriers should conform to the following requirements (AS 5100.1 – 2004):

- A transition road safety barrier should be provided on the approach to all bridge safety barriers.
- The strength and stiffness of the approach road safety barrier should vary to provide a transition from flexible road safety barrier to the rigid or semi-rigid bridge safety barrier.
- A smooth face and tensile continuity should be maintained throughout. Exposed rail ends, posts and sharp changes in the geometry of the barrier components, kerbs, and the like, should be avoided or transitioned out with a taper that reflects the values in Table 6.5.

Additional information on transitions between bridge and road barriers is provided in Section 16.1 of the *Guide to Bridge Technology – Part 3: Typical Superstructures, Substructures and Components* (Austroads 2009j).

6.3.24 Step B16 – Confirm that the Barrier Meets the Objectives

When the design has been completed it is prudent to re-visit the original objectives (Section 6.3.3) of providing the barriers and check that the design will perform the functions that led to the barrier being proposed. If there is doubt that the design is the best outcome to achieve the objectives the designer should consider whether an alternative type of barrier should be considered and return to Step B11 (Section 6.3.19) to continue the design process.

6.4 General Access Through Road Safety Barriers

The preferred practice is to avoid providing breaks in a road safety barrier. However, it may be necessary to consider breaks at locations where pedestrians cross the road, intersections, points of access to property and access points in medians. Where breaks are necessary barriers may be overlapped and where necessary, safe end treatments must be provided. Authorised emergency or temporary access through concrete barriers can be provided by the installation of a suitably crash tested system (e.g. fabricated sliding steel gate). An example of an overlapping type access through a barrier is shown in Commentary 14.

6.5 Road Safety Barriers for Vulnerable Road Users

The provision of a safe road environment for all road users, including motorcyclists, cyclists and pedestrians is an objective of all road authorities. Barriers and specific features of them can be very hazardous to motorcyclists who crash into the barrier, whether on the vehicle or not. The provision of inappropriately located and designed road safety barriers in close proximity to footpaths and bicycle facilities can also cause injury to pedestrians and cyclists.

6.5.1 Motorcyclists

A hazardous aspect of road safety barriers with respect to motorcyclists is exposed barrier posts, as their edges concentrate the impact forces resulting in more severe injuries to motorcyclists (ATSB 2000). Other barrier features that may be hazardous to motorcyclists (ATSB 2001) include:

- upper and lower W-beam edges
- protruding reflectors utilising metal componentry
- barrier systems that are too low as motorcyclists can be catapulted over barrier systems of insufficient height
- discontinuous or jagged barrier surfaces, such as concrete barriers with decorative designs, which present edges to concentrate the forces of impact
- rigid barriers (likely to be involved in front-on collisions) which require an impacting rider to absorb virtually all of the kinetic energy at impact.

These issues should be considered when designing roadsides and barriers on roads that carry significant numbers of motorcyclists (e.g. popular motorcycling routes). Some of these features can also be hazardous for cyclists and pedestrians who have to operate in close proximity to road safety barriers.

There has been no comprehensive crash-testing program undertaken that has compared the safety performance of a number of different barrier types in controlled conditions with respect to motorcyclists. It is therefore difficult to make comparisons between barrier types regarding this issue.

Apart from the issue of motorcyclist crashes with barriers it is preferable that roads are designed to keep motorcyclists on the road and to minimise hazards adjacent to the road. Such measures include:

- adequate and consistent skid resistance and elimination of loose gravel on road surfaces
- avoiding variations in superelevation through curves
- provision of a clear and smooth roadside (i.e. clear zone) to assist errant riders to recover or stop without serious injury
- ensuring that utility service covers are constructed and maintained so that they are flush with the road surface
- minimising the number of rigid road furniture supports adjacent to the road.

The most desirable design outcome for all road users is that an effective clear zone is provided so that a road safety barrier is not required.

Motorcyclist-friendly road safety barrier systems

A number of methods designed to improve existing road safety barriers to better protect motorcyclists have been developed (Koch & Schueler 1987, Sala & Astori 1998). The methods generally involve use of a proprietary product that may provide:

- additional rails or attenuation cushions on the lower section or other components of the barrier system so that motorcycle riders do not impact hazardous features including the posts
- posts that are less hazardous to motorcyclists by virtue of their lower strength and shape
- a specifically designed covering of energy absorbing material for existing posts
- devices to remove sharp edges (e.g. post caps).

The use of enhancements to barriers is a matter for the particular jurisdiction and may be conditional on crash testing and the proposed devices not creating other problems (e.g. related to debris or drainage). The use of barriers and devices to improve motorcyclist safety may be considered by jurisdictions, particularly on popular motorcycling routes and areas considered to be high-risk (e.g. on the outside of curves).

6.5.2 Pedestrians and Cyclists

Need for a safety barrier

Pedestrians or cyclists may require shielding by a road safety barrier in situations where they are considered to be exposed to a higher than normal risk of being struck by an errant vehicle. Where a pedestrian/cyclist facility either exists or is proposed for an existing site that has a run-off-road crash history an assessment of pedestrian, cyclist and bystander exposure should be undertaken so that crash reductions for alternative treatments can be considered.

For new works, the protection of pedestrians and cyclists from passing traffic may also be considered and should be investigated by undertaking a risk assessment to assess the likelihood of the encroachment of errant vehicles into proposed pedestrian/cyclist facilities.

When considering the need to protect pedestrians and cyclists at a site the designer should consider the combination of factors that would require shielding of the facility including the:

- number and type of path users (e.g. whether large numbers of people congregate in or pass through the area, the presence of primary school children)
- factors that make the site more hazardous than other sites along the road (e.g. road geometry and characteristics that would increase the risk of run-off-road events)
- type of traffic that may cause a run-off-road event to be particularly severe (e.g. high numbers of heavily laden freight vehicles).

Situations where a road safety barrier may be appropriate are:

- intermediate and high-speed roads where a path is within the clear zone
- heavily trafficked shared-use paths separated by less than 4 m from an adjacent heavily trafficked lane, especially if the geometry is substandard. However, designers should refer to Section 6.3.4 for discussion on lateral location issues.
- sites where there is expected to be large numbers of bystanders congregated adjacent to the road beyond the clear zone (e.g. schoolyard, sporting facilities) and the consequences of a crash are expected to be high.

Treatment options

A road safety barrier is also a hazard to motor vehicle occupants and if located closer to the road has a higher probability of being impacted by errant vehicles. Where practicable the preferred options for treatment are:

- design and management of the road to minimise the likelihood of encroachment into the roadside by motor vehicles
- location (or relocation for existing facilities) of the pedestrian bicycle facility away from the road where it has a low probability of encroachment by errant vehicles
- provision of a road safety barrier (where installed to protect bystanders consideration should be given to it being placed closer to the bystanders rather than the road in order to minimise the potential for vehicle impacts).

Cyclists and pedestrians may require a barrier to prevent them inadvertently running onto a traffic lane from an adjacent shared path (e.g. footpath on a bridge with high numbers of young pedestrians/cyclists). In cases where there is no need to protect path users from errant vehicles, or errant vehicles from roadside hazards, a pedestrian fence of a suitable height for cyclists should be adequate.

Design considerations

Where there is a need to provide a road safety barrier between a path and road traffic it is important that the rear of the road safety barrier is not a hazard for pedestrians and cyclists. Designers should ensure that:

- adequate clearance is provided between the rear of the road safety barrier and the path (refer to the *Guide to Road Design – Part 6A: Pedestrian and Cyclist Paths)* (Austroads 2009g)
- no sharp edges, burrs or other potential hazards (e.g. protruding bolts) exist
- where sufficient clearance cannot be provided, cyclists are protected from ‘snagging’ on posts by the provision of suitably designed rub rails
- where sufficient clearance cannot be achieved, consideration is given to the need to increase the height of the barrier either to prevent errant cyclists from falling over the barrier and into a traffic lane or to discourage pedestrians from jumping over the barrier to cross the road at an unsafe location.

Where sufficient space is available, a frangible pedestrian fence may be erected behind the road safety barrier at a distance that would accommodate the likely deflection of the barrier under impact by an errant vehicle. Adequate clearance is also required between pedestrian fences and bicycle paths and shared paths. In situations where space is restricted, it may be necessary to consider provision of a higher rigid barrier.

Designers should ensure that any modification or attachments to a barrier would not be detrimental to its performance under vehicle impact or result in components being hazardous to motorists or path users in the event of a crash with the barrier (e.g. horizontal rails spearing vehicles).

Where pedestrian facilities are incorporated behind a road safety barrier system, the desirable minimum height of the system is to be 1200 mm above the surface of the footway. Where provision for pedal cyclists is required, the desirable minimum height above the surface of the path should be 1400 mm.

Separate rails may be provided to meet these requirements provided they do not have the potential to spear through an impacting vehicle, create debris that poses a serious hazard, or change the characteristics of the system to the extent that crash outcomes are significantly altered.

Pedestrian and cyclist access through barriers

Preferred practice is to avoid providing breaks in a road safety barrier. However, it may be necessary to consider breaks at locations where pedestrians cross the road and where breaks are necessary, barriers may be overlapped and/or safe end treatments must be provided.

Bridges and overpasses

AS 5100.1 – 2004 provides information on barriers for bicycle and pedestrian bridges and for some design elements for bicycle/pedestrian paths as they relate to bridges.

Temporary barriers and roadworks

During roadwork activities, consideration needs to be given to provision of bike and/or pedestrian access through the works and temporary barriers may be required to provide protection with respect to road traffic and construction traffic. Other situations where provision of temporary barriers may be required include during special events where there is a need to physically control both vehicle and pedestrian movements.

6.6 Aesthetic Road Safety Barriers

In areas such as parks, historical communities and scenic areas, roads must not only provide safe and efficient access but also preserve the environmental and aesthetic qualities of the area. As operating speeds at these locations are generally much lower than on the general network, road safety barriers can be designed that satisfy both safety and aesthetics at reasonable cost.

Some of the more popular aesthetic systems comprise stone masonry walls and timber facing on steel barriers. In addition, the flexible wire rope barriers with their open design, installed on powder coated coloured posts, can also provide aesthetic solutions.

Textures that do not result in excessive vehicle damage may be considered acceptable for concrete vertical wall barriers or constant slope barriers. Alternative textures have been tested in the USA and found to be acceptable. Some guidelines for acceptable texture have been developed by the Federal Highway Administration (FHWA 2002).

6.7 Other Road Safety Barrier Design Considerations

6.7.1 Barriers at Intersections

Where intersections are located in close proximity to a bridge or tight curve, or are located on a substantial fill embankment, it may be necessary to run a semi-rigid barrier around the corner as described in Appendix L. Where the intersection is located close to a bridge, a properly designed and installed transition treatment is required to connect the barrier to the bridge barrier. In these situations it is essential that the barrier is located in a position where it does not impede sight distance. Sight distance requirements at intersections are covered in Section 3 of the *Guide to Road Design – Part 4A: Unsignalised and Signalised Intersections* (Austroads 2009d).

6.7.2 Orientation to Travel Lanes

Road safety barriers should be parallel to travel lanes wherever possible, to provide visual guidance to a driver that is consistent with the guidance provided by lane marking. The consistency of parallel guidance is particularly important at night.

6.7.3 Stepped Offset

Varying offsets to road safety barriers along a length of road may cause guidance problems at night. Varying offsets of delineators on barriers may be confusing in the dark because steps in the barrier offset create a broken line of reflectors that is not consistent with the lane marking. In such circumstances designers should consider omitting the delineators on barriers and use alternative delineation (e.g. raised reflective pavement markers and guideposts)

6.7.4 Excessive Offset

At night a large offset between a road safety barrier and the edge of the travelled way can give the impression that an extra lane is available between the edge line and the offset barrier. This may lead to crashes where drivers have moved onto the shoulder and verge in the mistaken belief that an extra lane is available. Alternative delineation should be provided closer to the road.

6.7.5 Delineation

The terminal ends of road safety barriers should be clearly delineated to avoid impact when drivers pull off the road, particularly at night. Delineation of the terminal ends of wire rope barriers is especially important because they are difficult to see both night and day.

Delineation on barriers can conflict with the guidance provided by guide posts and raised pavement markers. As noted above this may be a problem where a barrier is offset at close to a lane width from the travel lanes.

If a barrier is located beyond the edge of a shoulder then consideration should be given to the need for guideposts to define the area where it is safe to pull off the road.

6.7.6 Minimum Curve Radius for Wire Rope Barriers

The minimum curve radius for wire safety barriers is 200 m. Radii smaller than 200 m have problems with posts being pulled over when the wire rope is tensioned and 200 m is the only radius that has been crash tested (RTA 2003, RTA 2005).

6.7.7 Foundations

Reinforced concrete strip footings that have been structurally designed are acceptable to support road safety barrier systems where the relevant road authority has accepted a base plated post version.

Maintenance strips need to allow for the lateral movement of the posts with joints in the concrete. These also facilitate repair and replacement after impact.

Some soft soil conditions may be addressed by installing W-beam on 2100 mm thrie-beam posts in lieu of the standard 1800 mm posts.

6.7.8 System Height

An issue associated with barriers is the reduction in their height above pavement level when overlays or resurfacing are implemented. Reduction in the height of a barrier can adversely affect its operation, by increasing the risk of a vehicle vaulting the system.

Concrete barrier profile must not be placed on top of any kerb profile as this will raise the height of the system, generating the potential to roll small to medium-sized vehicles.

6.7.9 Blockouts on Steel Rail Systems

Twin blockouts on a W-beam post are acceptable on an isolated post only. More than two stacked blockouts has the potential to lift the rail as the post bends back during an impact.

7. Design for Steep Downgrades

7.1 Purpose and Need

Long, steep downgrades can result in the drivers of heavy vehicles losing control and it may therefore be desirable to take measures to prevent the occurrence of and limit the consequences of runaway heavy vehicles. Out-of-control vehicles result from drivers losing control because of the loss of brakes through overheating or mechanical failure or because the driver failed to change down gears at the appropriate time. When considering the provision of runaway vehicle facilities it is suggested that road authorities liaise with stakeholders with respect to the location, spacing and design of the facilities. Measures aimed at managing errant vehicles on steep descents include:

- alerting drivers of a steep descent on the approach to the downgrade
- regulating the use of a low enough gear to control the descent speed of heavy vehicles
- providing containment facilities for runaway vehicles.

Standard traffic signs exist to warn drivers of steep descents and to instruct drivers to use a low gear (refer to AS 1742.2 – 2009 or Transit NZ 2007).

7.2 Containment Facilities

Runaway vehicle containment facilities include the:

- gravity safety ramp
- arrester bed
- dragnet.

A combination of these facilities may be needed to suit a particular site. In addition, in some cases it may be desirable to place an energy absorbing barrier at the end of a safety ramp or arrester bed to cover an event where a vehicle has not totally decelerated within the ramp or bed (e.g. natural compaction of bed material reduces its effectiveness).

7.2.1 Gravity Safety Ramp

Gravity safety ramps use an ascending grade to reduce the speed of a runaway vehicle. Ramps are normally hard surfaced and take advantage of naturally occurring grades on a mountain range.

7.2.2 Arrester Beds

Arrester beds are long trenches filled with small round gravel particles that are designed to stop runaway trucks. The truck is stopped by drag and friction as the vehicle sinks into the gravel in the bed.

Arrester beds are classified as a:

- direct entry arrester bed
- side entry arrester bed – full width
- side entry arrester bed – half width.

7.2.3 Dragnets

A dragnet vehicle-arresting barrier consists of a chain link net that is attached to energy absorbing poles. Several nets in series are needed to capture heavy vehicles. Design of dragnet systems needs to be in accordance with the manufacturer's design parameters.

7.3 Warrant for Investigation

Downgrades have the potential to cause brake fade in heavy vehicles and can be considered for treatment to reduce the risk of runaway vehicles. Grade and length combinations that warrant investigation are shown in Table 7.1.

Table 7.1: Typical warrants for analysis for runaway vehicles

Grade	Minimum continuous length (km)
-3%	8.0
-5%	3.1
-7%	1.9
-9%	1.4
-12%	1.0

Source: RTA (2008).

Where a warrant has been established for investigation for treatment of a steep downgrade the design of treatments should follow the process in Section 7.6.

7.4 Location and Spacing

Runaway vehicle facilities should not be constructed where an out-of-control vehicle would need to cross oncoming traffic. On undivided roads safety ramps should ideally be located at the start of a right-hand curve as the runaway vehicle can readily negotiate a tangential path into the ramp. On divided roadways where adequate space is available in the median, safety ramps can be located on either side of the carriageway provided that adequate advance warning signs are erected prior to the safety ramp exit.

For safety ramps to be effective their location is critical. They should be located prior to or at the start of the smaller radius curves along the alignment. For example, an escape ramp after the tightest curve will be of little benefit if trucks are unable to negotiate the curves leading up to it. Vehicle brake temperature is a function of the length of the grade, therefore escape ramps are generally located within the bottom half of the steeper section of the alignment.

Lack of suitable sites for the installation of ascending type ramps may necessitate the installation of horizontal or descending arrester beds. Suitable sites for horizontal or descending arrester beds can also be limited, particularly if the downward direction is on the outside or fill side of the roadway formation.

For new projects Table 7.2 may be used as a guide when considering the need for escape exits on grades greater than 6% and with numbers of commercial vehicles exceeding 150 per day.

The distances in Table 7.2 are not absolute and greater distances could be acceptable, as site location is dependent on other factors. The need for a facility will be increased if the number of commercial vehicles is more than 250 per day and the maximum decrease in operating speed between successive geometric elements is approaching the limits set in Table 7.3.

Table 7.2: Approximate distance from summit to safety ramp

Grade (%)	Approximate distance from summit to the ramp (km)
6 – 10	3.0
10 – 12	2.5
12 – 15	2.0
15 – 17	1.5
17	1.0

Note: Actual distances will depend on site topography, horizontal curvature and costs.

Source: Austroads (2003).

Table 7.3: Maximum decrease in speed between successive geometric elements

Grade (%)	Maximum decrease in speed between successive geometric elements (km/h)
< 6	10
6 – 10	8
> 10	6

Source: Austroads (2003).

7.5 Key Design Considerations

The design, construction and maintenance of runaway vehicle facilities should ensure that the:

- Length of the escape ramp is sufficient to dissipate the kinetic energy of the vehicle.
- Alignment of the ramp is straight or of very gentle curvature to relieve the driver of undue vehicle control problems.
- Width is wide enough to accommodate two vehicles if it is considered likely that a second vehicle will need to use the ramp soon after the first one.
- Adequate work space is available for heavy vehicle removal (e.g. lifting cranes).
- Arrester bed material is clean, not easily compacted or consolidated and has a high coefficient of rolling resistance.
- Full depth of the arrester bed is achieved in the first 50 m of the entry to the bed using a tapering depth from 50 mm at the start to the full depth at 50 m.
- Bed is properly drained.
- Entrance to the ramp is designed so that a vehicle travelling at high speed can enter it safely. A 5º angle of departure or less is required, and as much sight distance as possible should be provided. The leading edge of the arrester bed must be normal to the direction of entry to ensure that the two front wheels of the vehicle enter the bed simultaneously.
- Signing is in accordance with the appropriate standard to alert the driver to the presence of the escape ramp. The location of signs, street lighting poles and overhead power lines should not obstruct the operation of the arrester bed or retrieval operations. Routine maintenance of any light poles should not impose any entry restriction to the arrester bed at any time.
- Facility, where necessary, has an emergency roadside phone with connection to an operations centre or emergency service placed in a visible and easily accessible location.

In addition, the following operational factors should be considered:

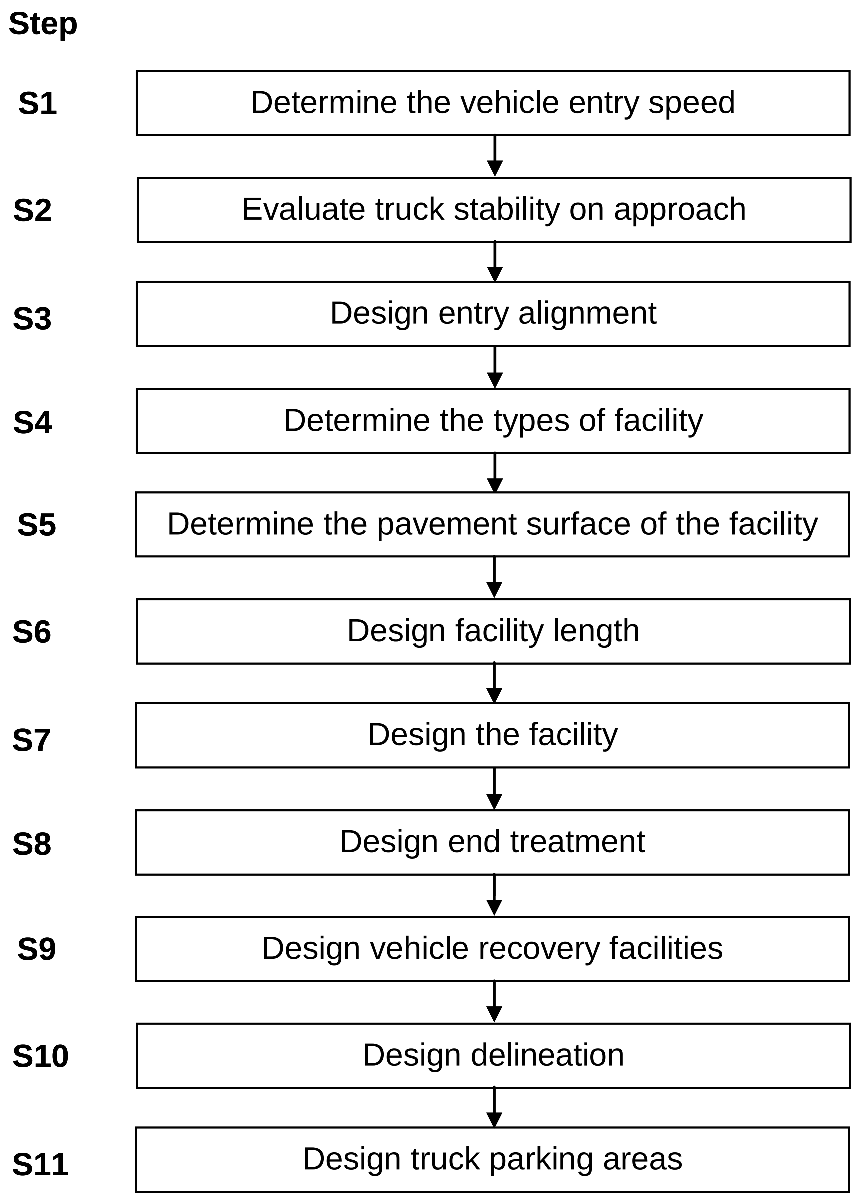
- The alignment of all curves preceding the ramp should be checked to ensure that a runaway vehicle can safely negotiate them at the speeds estimated to be likely.
- Vehicles that enter the ramp will have to be retrieved, as it is unlikely that they will be able to be driven from the arrester bed. An appropriate service road adjacent to the ramp is required to effect retrieval. An alternative and/or enhancement to the service road is the provision of anchorage points/blocks for winching vehicles out.
- When the location of the ramp is such that the length is inadequate to fully stop an out-of-control vehicle, a positive attenuation (or ‘last chance’) device may be required. Care is required to ensure that the device does not cause more problems than it solves – sudden stopping of the truck can cause the load to shift with potentially harmful consequences to the driver and the vehicle. Judgement will be required on whether the consequences of failing to stop are worse than these effects. Crash cushions or piles of sand or gravel have been used as last chance devices.

7.6 Design Process

7.6.1 Outline of Process

The steps in the design process for treatment of steep downgrades are shown in Figure 7.1. Steps S1 to S11 in the process are discussed in Sections 7.6.2 to 7.6.12 respectively.

Figure 7.1: Design process for steep downgrade



7.6.2 Step S1 – Determine Vehicle Entry Speed

The recommended design vehicle should be determined as part of the design process and should be used in determining the vehicle entry speed to the facility. Heavy runaway vehicles attain high speeds but speeds in excess of 130 to 140 km/h will rarely, if ever, be attained. An escape ramp should therefore be designed for a minimum entering speed of 130 km/h, a 140 km/h design speed being preferred. Several formulae and software programs have been developed to determine the runaway speed at any point on the grade. These methods can be used to establish a design speed for specific grades and horizontal alignments (AASHTO 2004).

7.6.3 Step S2 – Evaluate Truck Stability on Approach

The designer should check that the truck can reach the facility at the calculated speed and will not roll over on curves uphill of the runaway containment facility. The maximum cornering speed is given by Equation 6 and can be expressed as:

$$v = \sqrt{(agR)} \tag{6}$$

where

v = speed of vehicle (m/s)

a = maximum lateral acceleration 0.3g

g = gravitational constant 9.81 m/sec^2

R = radius of curvature.

If trucks are likely to roll over before reaching the containment facility then relocation of the facility should be considered, if the terrain allows.

7.6.4 Step S3 – Design Entry Alignment

The entry speed of a runaway vehicle is used for designing the approach and entry to safety ramps and arrester beds. The alignment of the escape ramp should be at a tangent or very flat curvature to reduce the likelihood that the driver will experience vehicle control problems. Designers should refer to the *Guide to Road Design – Part 3: Geometric Design* (Austroads 2009b) in designing the vertical and horizontal alignment of the treatment.

7.6.5 Step S4 – Determine Type of Facility

The constraints imposed by the terrain will largely determine the type of facility to be implemented. Several iterations of design may be necessary if a combination of facility types proves to be necessary. Changes to the type of facility and pavement type may be necessary to determine the best fit to the site constraints.

7.6.6 Step S5 – Determine Pavement Surface of Facility

The rolling resistance of the facility pavement will have a significant influence on the length required for the containment facility. The values shown in Table 7.4 (AASHTO 2004) are used for length calculations.

From field tests and other research studies, rounded particles such as uncrushed river gravel with uniform gradation produce higher deceleration than the more angular crushed aggregate. This is because the vehicles sink deeper into the river gravel, transferring more energy to the stones over a shorter length. The use of a material with low shear strength is desirable in order to permit tyre penetration.

Crushed stone has been used but is not considered effective as it will require longer beds and will need regular ‘fluffing’ or de-compaction.

Sand also has problems of drainage, compaction and contamination and should not be used unless alternative materials are unavailable. Beds using sand will require a strict maintenance regime to ensure their continued effectiveness. However, all arrester beds and bedding materials require regular maintenance.

Nominal 10 mm river gravel has been used satisfactorily in testing. The gravel should be predominantly rounded, of uniform gradation, free from fine fractions and with a mean particle size ranging between 12 mm and 20 mm. In general, gravels with a smaller internal friction angle will perform better than those with larger internal friction angles.

An appropriate crush test such as the Los Angeles abrasion test (or equivalent) should be used to evaluate durability of the stone. Stones with a high crush test will not deteriorate and will therefore not produce fines.

Table 7.4: Rolling resistance

Material	Rolling resistance (kg/1000 kg gross vehicle mass) (R)	Equivalent grade (%)
Cement concrete pavement	10	1.0
Asphaltic concrete pavement	12	1.2
Compacted gravel	15	1.5
Earth, sandy, loose	37	3.7
Crushed aggregate, loose	50	5.0
Gravel loose	100	10.0
Sand	150	15.0
Pea gravel	250	25.0

Note: Pea gravel is rounded gravel having a uniform particle size of about 10 mm.

Source: AASHTO (2004).

7.6.7 Step S6 – Design Facility Length

The length of a containment facility will vary depending on entry speed, grade, pavement surface and the type of facility.

The vehicle entry speed described in Section 7.6.2 is used as the initial velocity for determining the length of an arrester bed. The length of an arrester bed (RTA 2000) is given by Equation **7** and is expressed as:

$$L = \frac{Vi^2 - Vf^2}{2.54(R+G)} \tag{7}$$

where

L = length travelled (m)

Vi = initial velocity (km/h)

Vf = final velocity (km/h)

R = grade in percent

G = rolling resistance expressed as a grade in percent from Table 7.4.

Where there is a grade change in the arrester bed, Equation 7 can be used to calculate the length required on each grade. The final velocity of a section becomes the initial velocity of the next section.

The length of a half-width arrester bed is double the length of a full-width arrester bed.

7.6.8 Step S7 – Design the Facility

General

This step requires the preparation of the layout and design of the facility. Several iterations with different combinations of facility types may be necessary.

Safety ramp design features

The grade of the safety ramp will be largely determined by the terrain. Safety ramps need steep-sided cut batters on both sides. When a runaway vehicle stops in a ramp it will begin to roll back because the brakes are not functional. In this situation drivers must jack-knife the vehicle against the sides of the ramp to prevent it rolling down the ramp.

Arrester bed design features

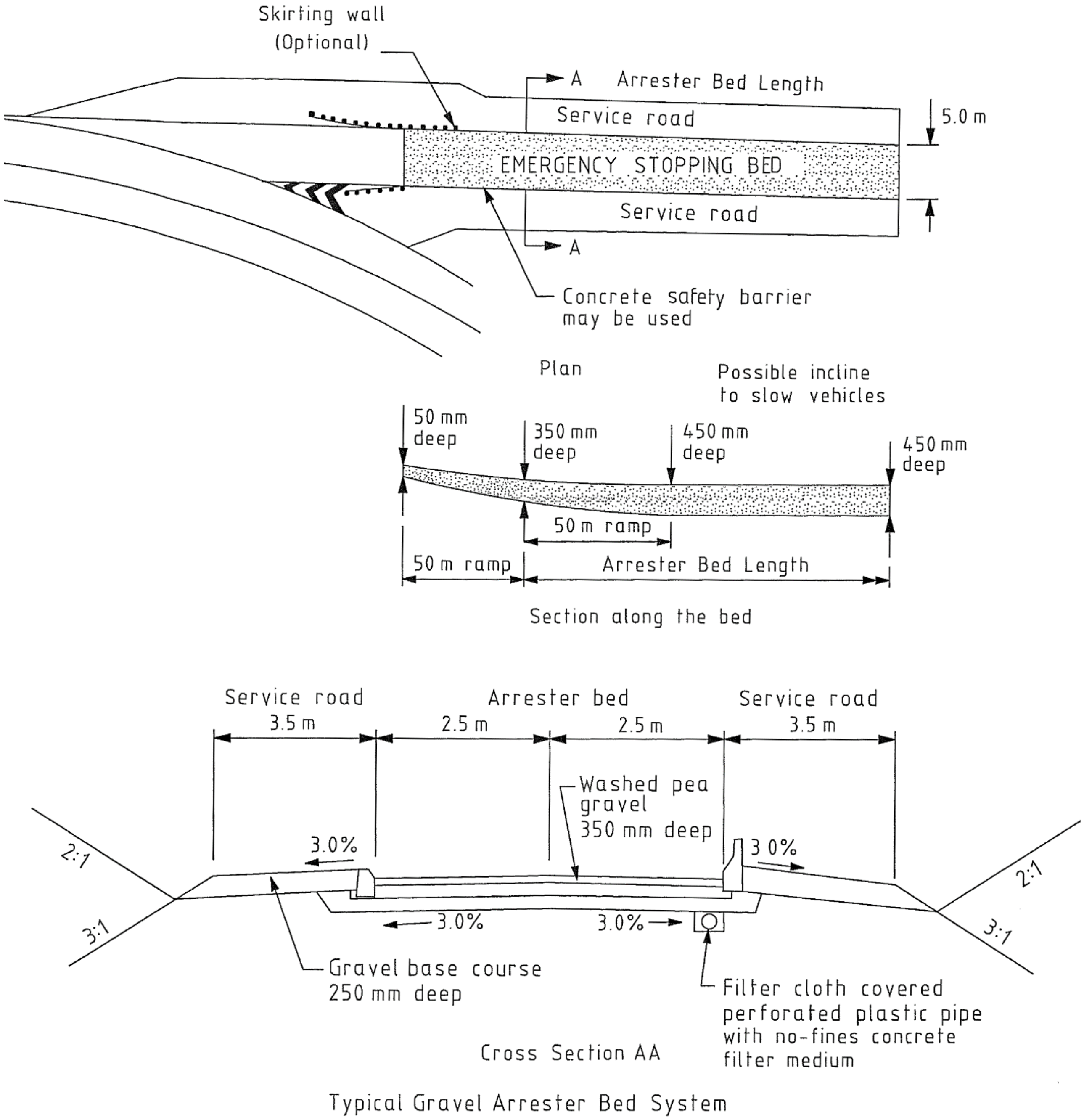
Arrester beds aim to provide deceleration similar to an emergency braking situation to avoid the risk of the truck cabin being crushed by a shifting load. Arrester beds can be constructed on up, level or downgrades depending on the topography at the site (refer to Commentary 15). Arrester beds on downgrades require additional length to bring out-of-control vehicles to rest. An example of an arrester bed is shown in Figure 7.2 while Figure 7.3 shows an example of a layout.

It can be seen from Figure 7.2 that a working area for a retrieval vehicle or crane is provided only on one side of the bed whereas the example layout in Figure 7.3 shows a service road on both sides. An access area on both sides of the arrester bed will not be necessary in many cases but may be required where heavy vehicles on a route carry very heavy or difficult loads that require retrieval vehicles or cranes to work from both sides.

Figure 7.2: An example of an arrester bed

Source: RTA (2008).

Figure 7.3: An example of an arrester bed layout



Source: Austroads (2003).

Table 7.5 provides a summary of the features associated with arrester beds and key considerations required in design.

Table 7.5: Design features of arrester beds

Feature	Consideration
Horizontal alignment	Some steering is possible in a gravel arrester bed. Where a curve is necessary the radius should be generous, well in excess of standard travel speed to radius ratio.
Lateral location	The round gravel sprayed or dislodged from the arrester bed may be a hazard to passing vehicles as it is likely to cause crashes due to loss of steering and traction on adjoining traffic lanes. An arrester bed should be located more than 4 m from travel lanes. This offset provides an access area for recovery vehicles and provides a space for containment of sprayed gravel. An alternative is to provide a kerb at an offset to the travel lane to contain gravel that would be swept onto travel lanes. Kerbs should not prevent a grader with blade extension being used to recover and grade gravel after a vehicle has been removed from the arrester bed.
Width	A width of 5 m gives some room for steerage yet should control a heavy vehicle if it starts to get out of control within the bed.
Depth	A gradual or staged increase in the depth of the bed should be provided on the entry ramp. There should be a gradual increase in aggregate depth in the first 30 m although the initial depth of the aggregate need not start at zero. This gradual increase also assists in vehicle extraction. A maximum bed depth of 350 mm provides adequate deceleration without causing damage to the vehicle. Higher deceleration rates can be achieved by increasing the bed depth up to 450 mm; however, driver safety may be jeopardised and damage may be caused to the vehicle. An increase in depth to 450 mm depth at the end of the bed will provide for higher-speed vehicles to be arrested at the point where vehicle speed has been reduced by the treatment.
Base	The base of an arrester bed should be concrete with a crossfall of 2% falling towards the concrete barrier and graded to a drainage system. Steeper crossfalls should not be used as they cause trucks to veer off-line as they pass through the arrester bed.
Barrier	A vertical concrete barrier should be placed on the edge of the bed furthest from the travel lane to assist in keeping vehicles travelling along the bed.
Drainage	Stormwater should be directed away from the bed. The base of the bed should be designed to accommodate drainage to help protect the bed from freezing and avoid contamination of the arrester bed material by accumulation of fines that would compact the bed material. Installation of perforated drains in the base of the bed and lining the bed base and sides with asphalt or cemented material is required.
Fuel spill containment	Truck fuel lines may be ruptured when impacting the gravel in an arrester bed. The drainage system of the arrester bed should be fitted with a fuel spill containment facility.
Arrester bed material	Rounded pea gravel in loose condition is essential to make an arrester bed effective. The aggregate should be predominantly single sized and uniform. It should be clean, free of fines and have smooth rounded surfaces. The recommended specification is shown in Table 7.6. Deceleration characteristics of the bedding material may be affected by wet weather.

Table 7.6: Arrester bed material specification

Criteria	Percent passing AS sieve (%)
Percent passing 19 mm AS sieve	100%
Percent passing 9.5 mm AS sieve	0 – 5%
Percent passing 0.075 mm AS sieve	Maximum 2%
Fractured faces	Maximum 10%
2/1 Misshapen particles	Maximum 10%
Crushing	Not greater than 5%
Cracking	Not greater than 5%
Slump angle	Not greater than 30°
Bulk density	Not greater than 3.4 tonnes/cum

Note: Washed and screened uncrushed river gravel could meet this specification.

7.6.9 Step S8 – Design End Treatment

The consequences of a vehicle passing through and out of the ramp or arrester bed should be considered. Crash cushions are designed for cars and have limited effectiveness for trucks. They should only be considered where they would act as a cushioning device before a rigid object such as a rock face.

A dragnet system may be needed if a ‘fail-safe’ end treatment is not available.

7.6.10 Step S9 – Design Vehicle Recovery Facilities

Access and anchors for cranes and/or tow trucks should be designed and provided to facilitate removal of the disabled vehicle from the containment facility. The design of removal facilities should ensure the occupational health and safety of removal workers.

Safety ramp recovery facilities

If separate access is available to the top of the ramp a tow truck can be used for vehicle recovery. A large anchor block should be buried below the surface at the top of the ramp as recovery will be assisted if the tow truck can be chained to an anchor while winching the runaway vehicle up the steep slope.

If access is not available to the top of the ramp it will be necessary to use a bulldozer to engage the rear of the runaway vehicle and lower it backwards down the slope and hence the treatment should be designed for this loading.

Arrester bed recovery facilities

To facilitate recovery of vehicles from an arrester bed a service road adjacent to the bed must be provided with a minimum width of 3.5 m. Access to the service road should be available for either two heavy-duty tow trucks or two 50 tonne capacity cranes and therefore the pavement of the service road should be capable of supporting 50 tonne capacity cranes. The service road should also be designed so a grader with blade extension can grade the gravel after a vehicle has been removed.

Anchor blocks are required to secure tow trucks while winching vehicles out of the arrester bed. Anchor blocks are to be located at 35 m intervals along the service road and 10 m from the entry and end of the arrester bed. Anchors should be designed to a 35 tonne winching force through an attachment shackle rated to withstand the design load. Attachment shackles should be recessed flush with pavement levels.

It is preferable that recovery is made from the exit end of the arrester bed as articulated vehicles will jack-knife if dragged backwards through the bed.

To enable drivers to get assistance, CB radio frequency or telephone numbers for emergency service may be advised on signposting adjacent to the bed or service road.

7.6.11 Step S10 – Design Delineation

The existence and location of a containment facility must be made obvious by signage to give the operator of an out-of-control vehicle time to react and decide to enter the facility. Standard signs should be provided and located in accordance with AS 1742.2 – 2009 or Transit NZ (2007). Signs that are likely to be required are those that:

- warn or advise of a steep descent
- provide advance notification of the facility
- indicate direction at the facility entrance
- advise truck and bus drivers to use a low gear.

Adequate delineation should also be provided so that the entrance to a containment facility is not mistaken for the through carriageway and the entry path to the facility is clear by day and night.

7.6.12 Step S11 – Design Truck Parking Areas

Truck parking areas before steep grades provide an area for truck drivers to stop and check the brakes of the vehicle. This area is also called a brake check area. A brake rest area, however, is an area set aside part-way down or at the bottom of the decent.

These areas enable truck drivers to stop and allow brakes to cool before the descent is negotiated. Brake check areas would naturally be on the top of a hill and should be easily accessible to heavy vehicles. Good sight distance should be available at both entry and exit.

The area available will vary with the number of trucks using the route. Long stays in these areas should be discouraged. Other truck rest stops should be available within a reasonable distance of the brake check parking area.

These facilities should be provided on routes that have long, steep downgrades and commercial vehicle numbers that exceed about 100 per day, especially on National Highways and principal traffic routes. These areas:

- ensure that drivers begin the descent at zero velocity and in a low gear that may make the difference between controlled and out-of-control operation on the downgrade
- provide an opportunity to display information about the grade ahead, escape ramp locations and maximum safe descent speeds
- may need to be large enough to store several prime mover and semi-trailer combinations, the actual numbers depending on volume and predicted arrival rate
- should desirably have a sealed surface, or at least a well-compacted gravel surface.

Good visibility to the areas and adequate acceleration and deceleration tapers should be provided.

Adequate signage should be provided to advise drivers in advance of the facilities. Special signs, specific to the site, may need to be designed.

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Appendix A Terminology

A.1 General Terms

A.1.1 Key Words

The key words in dealing with design for errant vehicles are:

Errant / adj. 1. deviating from the regular or proper course; erring. 2. moving in an aimless or quickly changing manner.

Design / v.t. to prepare the preliminary sketch or the plans for (work to be executed).

Hazard / n. 1. a risk; exposure to danger or harm. 2. the cause of such a risk; a potential source of harm, injury, difficulty.

A.1.2 Other General Engineering and Road Safety Terms

Other general terms are listed in Table A 1.

Table A 1: Terms in risk management

Term	Explanation
AADT	Annual average daily traffic.
Arrester bed	An area of land adjacent to the road that is filled with granular material to decelerate and arrest errant vehicles.
Clear zone	A clear zone is the area adjacent to the traffic lane that should be kept free from features that would be potentially hazardous to errant vehicles. The clear zone is a compromise between the recovery area for every errant vehicle, the cost of providing that area and the probability of an errant vehicle encountering a hazard. The clear zone should be kept free of non-frangible hazards where economically and environmentally possible. Alternatively, hazards within the clear zone should be treated to make them safe or be shielded by a safety barrier (Austroads 2008a).
Consequences	In relation to risk analysis, the outcome or result of a risk being realised.
Crash	An event or series of events resulting from a vehicle colliding with a person, object or another vehicle, likely to cause property damage, serious injury or death to vehicle occupants or to persons struck.
Errant vehicle	A vehicle that leaves the travelled path and runs off the side of the road or into the median.
Hazard Corridor	Concept used by RTA in NSW instead of the clear zone The horizontal width of space available for the safe use of an errant vehicle measured from the nearest edge of the relevant traffic lane.
Exposure factor	The estimated proportion of time that a specified exposure scenario applies.
Frequency	A measure of likelihood expressed as the number of occurrences of an event in a given time or in a given number of trials. See also Likelihood and Probability.
Hazard (General)	Threat, a source of potential harm or a situation with potential to cause loss.
Hazard (Roadside)	Any object or feature located between the edge of traffic lane and road reserve boundary, or within a median, that could cause significant personal injury (including fatal injury) to vehicle occupants when impacted by an errant vehicle.
Likelihood	Frequency of occurrence. A qualitative description of probability and frequency.
Probability	Confidence in an outcome. A measure of the degree of confidence in a prediction, as dictated by the evidence, concerning the nature of an uncertain quantity or the occurrence of an uncertain future event. An estimate of the likelihood of the magnitude of the uncertain quantity, or the likelihood of the occurrence of the uncertain future event. This measure has a value between zero (impossibility) and 1.0 (certainty).

Term	Explanation
Risk benchmarking	Comparing risks to a measured risk benchmark for the activity being considered. Risks above the benchmark are tolerable only if risk reduction is impracticable or if its cost is grossly disproportionate (depending on the level of risk) to the improvement gained.
Risk	The measure of the probability and severity of an adverse effect to life, health, property, or the environment. In the case of errant vehicles, risk is estimated by the combined impact of: • initiating event (errant vehicle) • hazardous effect (vehicle impacts hazard) • hazardous consequences (injury/death, lost time, crash costs).
Risk assessment	The processes of reaching a decision or recommendation on whether risks are tolerable and present risk control measures are adequate, and if not, whether alternative risk control measures are justified or will be implemented.
Risk management	The systematic application of management policies, procedures and practices to the tasks of identifying, analysing, assessing, controlling and monitoring risk.
Risk mitigation	A selective application of appropriate techniques and management principles to reduce either likelihood of an occurrence or its consequences, or both.
Safety ramp	A ramp designed to stop out-of-control vehicles, usually trucks, by using upgrades or gravel arrester beds or a combination of both.
Shy line	The distance from the edge of the travelled way beyond which a roadside object will not cause a driver to change their vehicle's lateral placement or speed.
Societal risk	The risk of widespread or large-scale detriment from the realisation of a defined hazard on such a scale as to provoke a socio/political response, and/or that the risk provokes public discussion and is effectively regulated by society as a whole through its political processes and regulatory mechanisms.
Tolerable risk	A risk level that society can live with to secure certain net benefits. A level that is not regarded as negligible or as something to ignore, but kept under review with a view to reducing it still further if possible.
Travelled way	That part of a road made available to vehicles in a particular direction. May consist of one or more running lanes.
Work zone	A section of road where roadworks are taking place. Defined by signposting and delineation.
85th percentile	85% of all recorded values will be less than or equal to the value nominated.

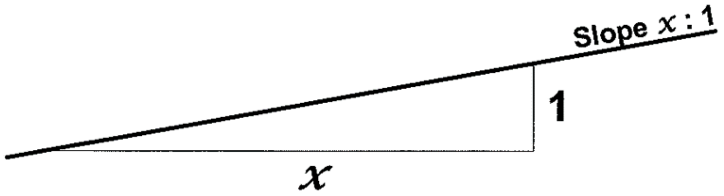
Source: Based on RTA (2008). Partly based on terms taken from Australian National Committee on Large Dams (ANCOLD) Guidelines on Risk Assessment (2008).

A.2 Expression of Slopes

Throughout this document, slopes are expressed as follows:

- ***For slopes in general:*** As a distance to height ratio (4:1 is equivalent to a running distance of 4 metres in a height of 1 metre). This is shown in Figure A 1.

Figure A 1: Expression of slope gradient



- ***For gentle slopes***: As a percentage. This is used for crossfalls and superelevation, and for tapers in plan view. For example, a 5% slope is equivalent to a ratio of 20:1.

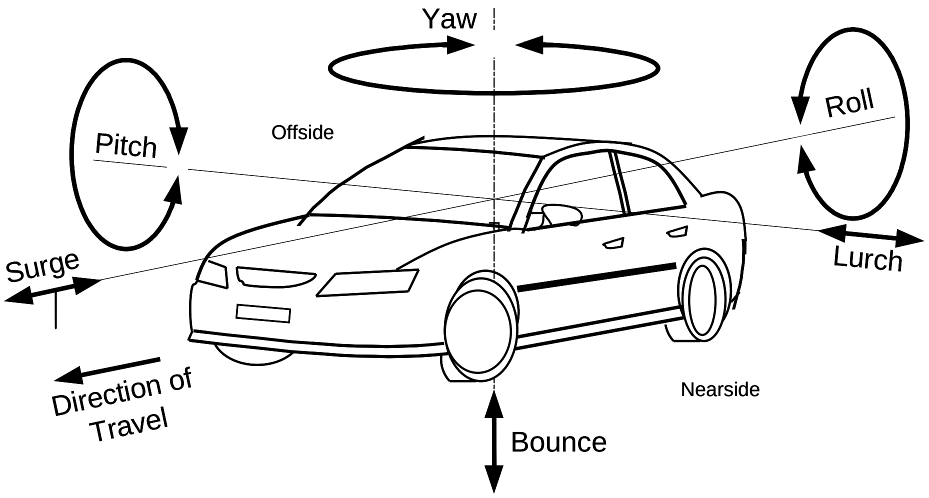
A.3 Vehicle Movement Terminology

The vehicle movement terminology is described in Table A 2 and illustrated in Figure A 2.

Table A 2: Vehicle movement terminology

Term	Meaning
Pitch	The rotation of a vehicle around its transverse axis.
Roll	The rotation of a vehicle around its longitudinal axis.
Yaw	The rotation of a vehicle around its vertical axis.
Spin	Uncontrolled yaw.
Lurch	The acceleration of a vehicle along its transverse axis.
Surge	The acceleration of a vehicle along its longitudinal axis.
Bounce	The acceleration of a vehicle along its vertical axis.

Figure A 2: Vehicle movement terminology



A.4 Road Safety Barrier Terminology

Table A 3 summarises road safety barrier terminology.

Table A 3: Road safety barrier terminology

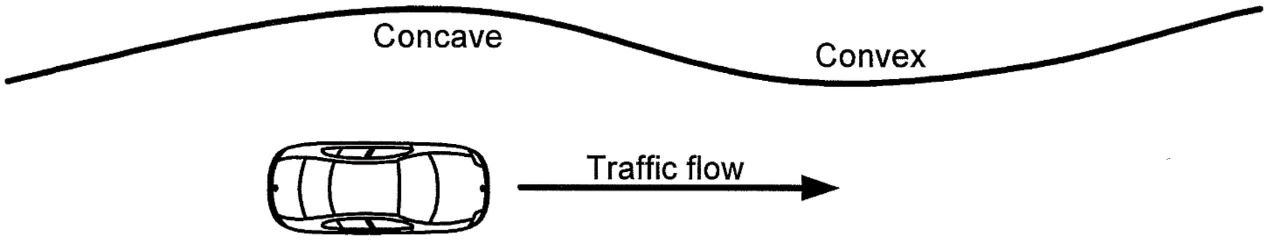
Term	Explanation
Concave	Road safety barrier curvature away from the adjacent traffic lane, i.e. inside the curve (Figure A 3).
Containment	The maximum tested vehicle mass used in a set of standard crash tests.
Convex	Road safety barrier curvature towards the adjacent traffic lane, i.e. outside the curve (Figure A 3).
Crash attenuator	Devices that prevent an errant vehicle from impacting hazardous objects by gradually decelerating the vehicle to a safe stop or by directing the vehicle away from the hazard. They are often used as the end treatment on the leading end of a road safety barrier system.
Crash cushion	An energy absorption device installed in front of a rigid object to reduce the severity of impact.
Departure angle	The angle at which the vehicle leaves the road safety barrier after initial impact (Figure A 4).

Term	Explanation
Development length	A length of unanchored road safety barrier, in advance of the point of need, that is necessary to provide sufficient mass for the barrier within the length of need to perform in accordance with its design parameters.
Double-sided road safety barrier	A road safety barrier designed for impact on both sides.
Dynamic deflection	The largest transverse deflection of a road safety barrier system during an actual crash or during a full-scale impact test (i.e. the amount the road safety barrier deflects from its initial position during impact, (Figure A 4).
Exit trajectory	The path followed by the vehicle after last impact with the road safety barrier (Figure A 4).
Flare	The change in the offset of a road safety barrier to move it further from the travelled way or closer to the travelled way.
Flare rate	The curvature applied near the end of a road safety barrier installation (Figure 6.5). Expressed as the ratio of the longitudinal distance to the transverse offset, by which a road safety barrier flares away from, or towards, the edge of the travelled way.
Gating terminal	A road safety barrier terminal designed to allow an impacting vehicle to pass through the device. Terminals that are designed to break away, pivot or hinge, and allow a vehicle to pass through when impacted at an angle to the end, or at a point upstream of the beginning of the length of the associated road safety barrier system.
Impact angle	The minimum angle at which a vehicle at speed leaves the road (Figure A 4).
Initial lateral position	The lateral position of the vehicle prior to initial change of direction (Figure A 4).
Interface	The length of road safety barrier system used to connect systems with different operating characteristics, commonly used to connect a non-rigid road safety barrier system to a rigid road safety barrier system, such as a bridge safety barrier.
Lateral re-direction	The lateral position of the vehicle after impact (Figure A 4).
Leading point of need	In relation to a roadside hazard, the first point at which the road safety barrier is needed to prevent an errant vehicle from striking the hazard (Figure A 5 and Figure A 6).
Leading terminal	The terminal treatment at the end of a road safety barrier that faces vehicles approaching in the adjacent traffic lane (Figure A 5 and Figure A 6).
Length of need	The length of a road safety barrier system, excluding leading or trailing terminals, needed to prevent errant vehicles from impacting a hazard, representing the length over which a road safety barrier will re-direct an impacting errant vehicle. It is the distance between the leading and trailing points of need - effectively the length of the road safety barrier less terminals (Figure A 5 and Figure A 6).
Median application	A road safety barrier system when it is installed in a median location. Can be impacted from both sides.
Nearside	The side of a vehicle closest to the kerb on the left-hand side of the road when the vehicle is travelling in the normal direction of travel.
Non-gating terminal	A road safety barrier terminal that is designed to re-direct or contain an impacting vehicle and absorb part of the energy of the impacting vehicle at any point along the terminal without allowing it to pass through the device.
Non-redirective crash cushion	A crash cushion designed to contain and capture an impacting vehicle.
Non-rigid road safety barrier system	A road safety barrier system where elements are designed to move substantially in a crash, and where energy is absorbed by movement of the road safety barrier system and deformation of the vehicle.
Offside	The side of a vehicle furthest away from the kerb on the left side of the road when the vehicle is travelling in the normal direction of travel (i.e. it corresponds to the driver’s side of the vehicle).
Permanent deformation	The permanent deformation of the road safety barrier that remains after impact (Figure A 4).
Permanent road safety barrier	A road safety barrier that is installed permanently at the roadside.

Term	Explanation
Point of impact	The point where the vehicle first impacts a road safety barrier (Figure A 4).
Point of need	The start or end of the length of need, defining the length over which an errant vehicle is redirected by the road safety barrier and would otherwise strike the hazard if a road safety barrier was not provided.
Post-impact speed	The speed of the vehicle following impact (Figure A 4).
Pre-impact speed	The speed of the vehicle before a change of direction (Figure A 4).
Proprietary system	A road safety barrier system that is the subject of patent or other intellectual property rights within Australia and New Zealand.
Public domain system	A road safety barrier system that is not the subject of patent or other intellectual property rights within Australia and New Zealand.
Redirective crash cushion	A crash cushion designed to contain and redirect an impacting vehicle.
Rigid road safety barrier system	A road safety barrier where there is no observable dynamic deflection during a vehicle impact. The deformation is contained within the impacting vehicle.
Road safety barrier system	A roadside device that provides a physical restriction to penetration of a vehicle in a way that reduces the risk to vehicle occupants and other traffic. Its purpose is to redirect or contain an errant vehicle. It is used to shield roadside obstacles or non-traversable terrain features. Occasionally, it may be used to protect people from vehicular traffic.
Secondary impact angle	The angle at which the vehicle impacts the road safety barrier for the second time (Figure A 4).
Single–sided road safety barrier	A road safety barrier designed for impact on one side only.
System width	The front to back dimension of the road safety barrier including its supporting posts, etc. (Figure A 4). This dimension should be less than the working width so that the system will not impact the hazard.
Temporary road safety barrier	A road safety barrier that is readily removable and used at roadworks, emergencies or similar situations.
Terminal	A device designed to treat the end of a road safety barrier. The terminal may function by decelerating a vehicle to a safe stop within a relatively short distance, or permit controlled penetration of the vehicle behind the device, or contain and redirect the vehicle, or a combination of these performance characteristics.
Test level (TL)	A set of conditions, defined in terms of vehicular type and mass, vehicular impact speed and vehicular impact angle that quantifies the impact severity of a matrix of tests.
Thrie-beam	A triple corrugated steel rail road safety barrier supported on steel posts.
Trailing point of need	In relation to a roadside hazard, the last point at which the road safety barrier is needed to prevent an errant vehicle from striking the hazard (Figure A 5 and Figure A 6).
Trailing terminal	The terminal treatment at the departure end of a road safety barrier in the direction of travel in the adjacent traffic lane (Figure A 5 and Figure A 6).
Transition	The connection of two road safety barriers of different designs and/or performances.
Vehicle roll allowance	The lateral distance between the deflected face of a road safety barrier and the maximum extent of vehicle body roll during impact.
W-beam	A double corrugated steel rail road safety barrier supported on steel posts.
Wire rope road safety barrier	A road safety barrier system consisting of wire rope cables under high tension that are supported on posts and anchored at the ends.
Working width	The minimum width that is required to prevent an impacting design vehicle from colliding with an object behind a road safety barrier system. This includes both the dynamic deflection of the road safety barrier (if any) and the extra width to allow for the roll (vertical rotation) of an impacting vehicle. This ensures that that the system width can be accommodated between the deformed road safety barrier and the hazard during impact (Figure A 4) and that the top of a high heavy vehicle will not impact a high hazard during impact.

The terminology associated with road safety barrier curvature is shown in Figure A 3.

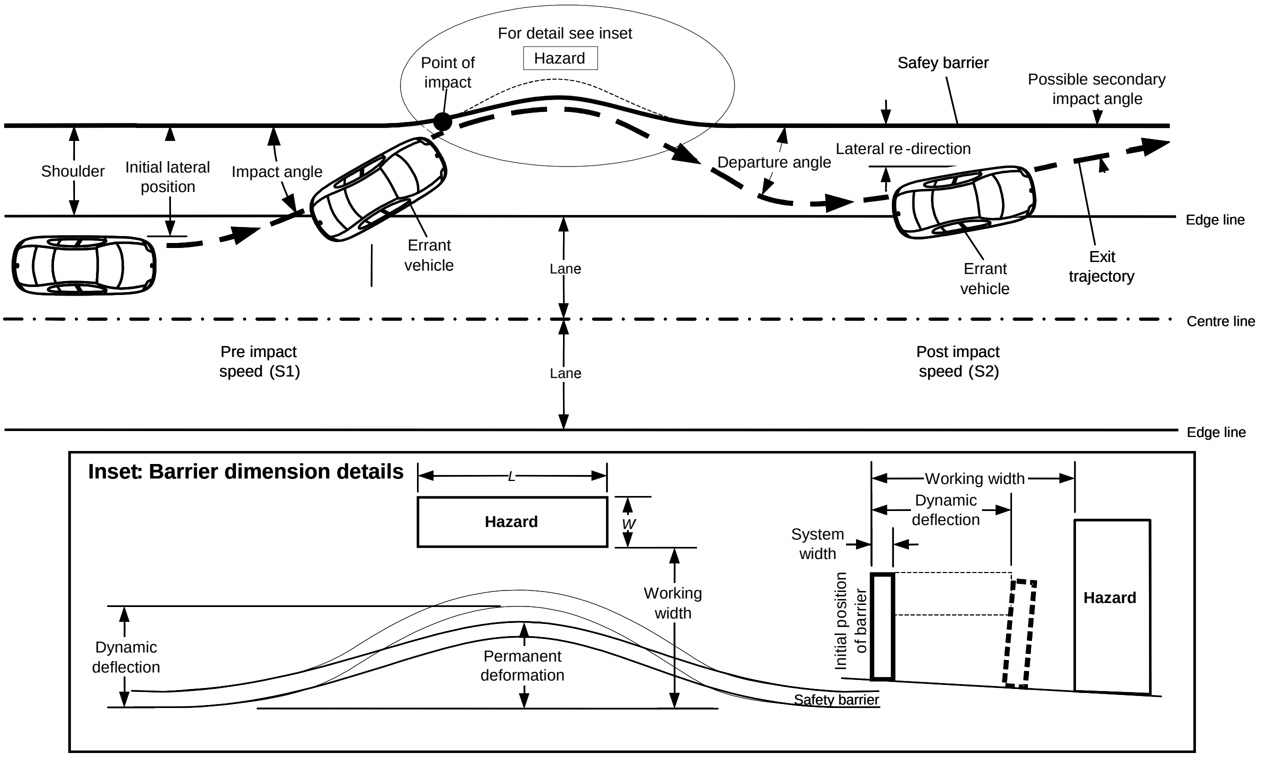
Figure A 3: Road safety barrier terminology – curvature



Source: RTA (2008).

The terminology associated with road safety barrier impact is shown in Figure A 4.

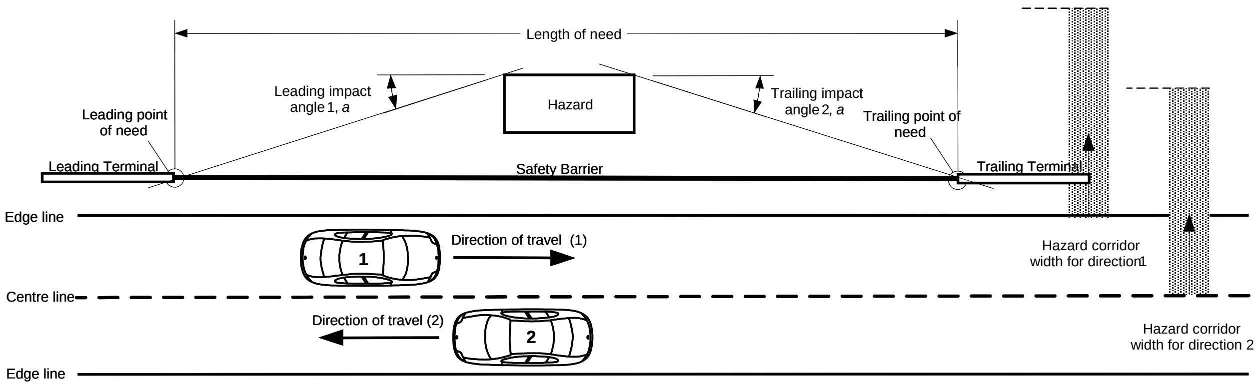
Figure A 4: Road safety barrier terminology – impact



Source: RTA (2008).

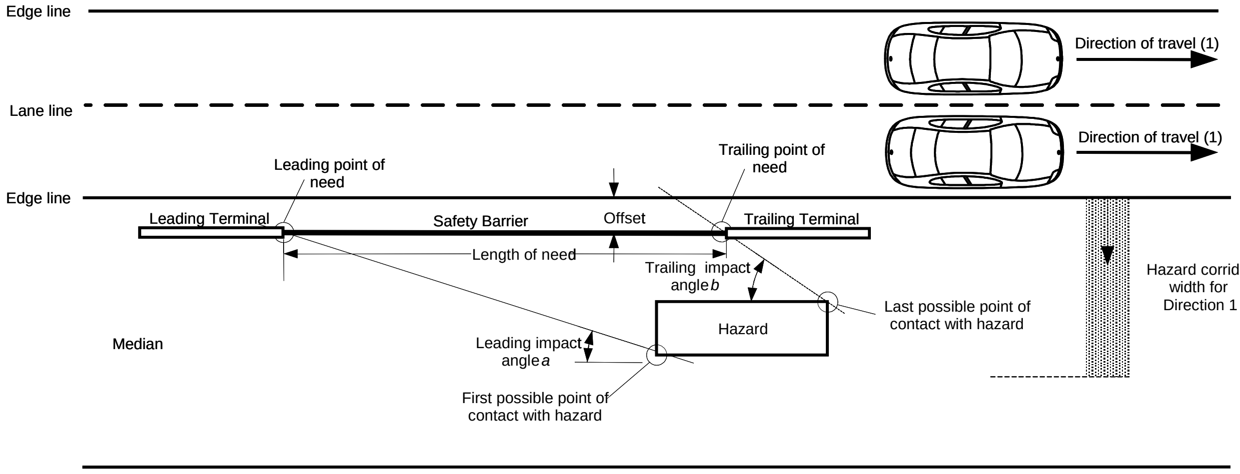
The terminology associated with road safety barrier placement is shown in Figure A 5 and Figure A 6.

Figure A 5: Road safety barrier terminology – placement on two-lane/two-way road



Source: RTA (2008).

Figure A 6: Road safety barrier terminology – placement on multi-lane/one-way road

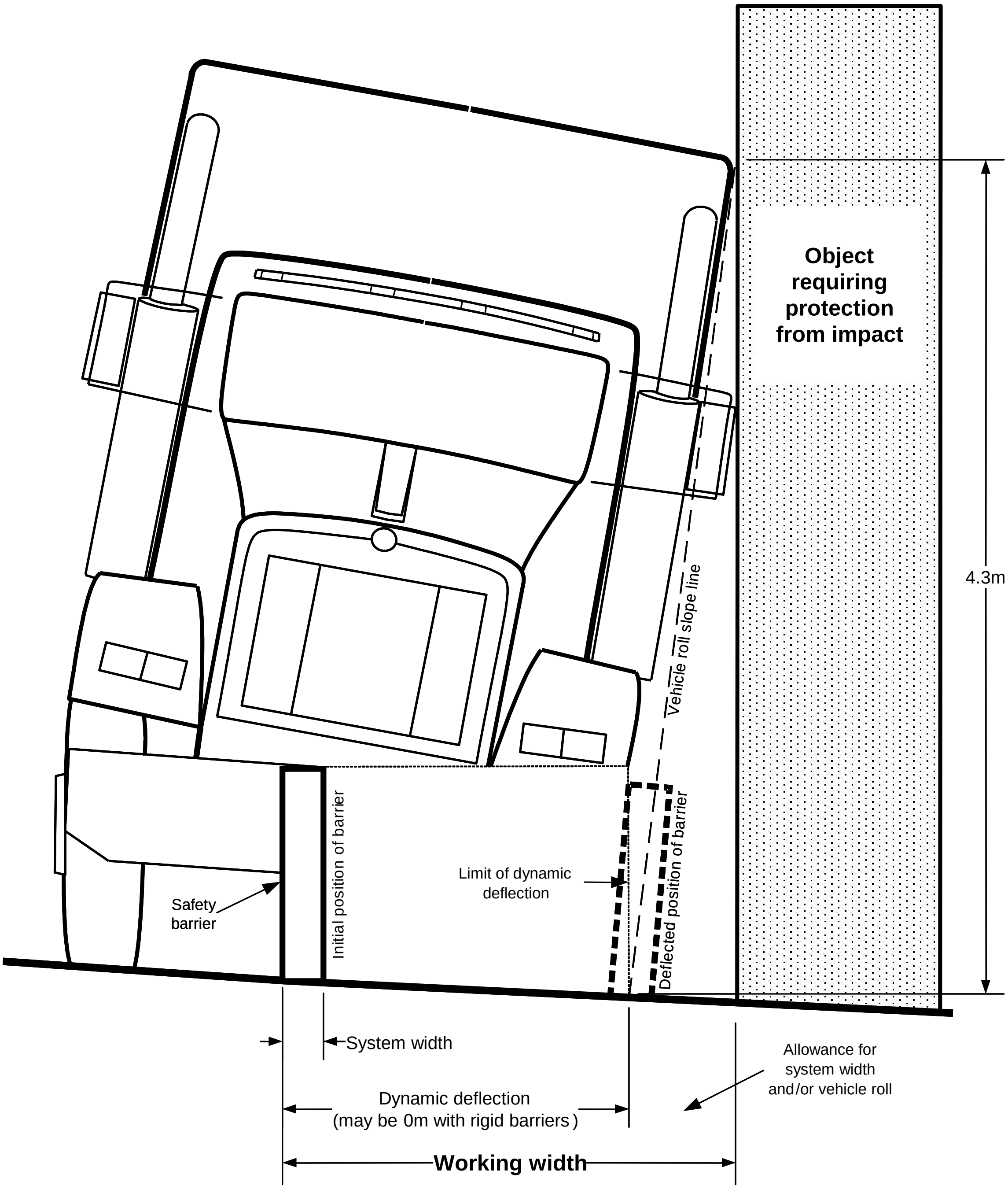


Source: RTA (2008).

A.5 Working Width and Dynamic Deflection

The clearance required between the face of a road safety barrier and a hazard includes the dynamic deflection of the road safety barrier system and a vehicle roll allowance and is described with the term working width as shown in Figure A 7.

Figure A 7: Working width



Source: RTA (2008).

Appendix B Hazard Mitigation Worksheet

The hazard mitigation worksheet in Table B 1 is provided as a framework for calculations and decisions relating to hazard mitigation. The table is based on RTA (2008). Whilst the table can be used to facilitate the process of hazard identification, evaluation of treatments for hazards, and the choice of options, it necessarily will be supplemented by other documents and calculations (e.g. computer software outputs) of benefit/cost ratios etc.

Table B 1: An example of a hazard mitigation worksheet

ID	Input data	Reference	Result
[A]	**Design Step D1: Determine Area of Interest**	**Section 4.2**	
[A1]	Chainage where width is assessed.	Plans.	
[A2]	Side of travelled way (verge/left or median/right).	Plans.	
[A3]	Design speed (km/h).	Brief.	
[A4]	Curve radius (m) (adjustment factor Table 4.2).	Plans.	
[A5]	Fill or cut batter.	Plans.	
[A6]	Batter slope.	Plans.	
[A7]	Clear zone. *[A3], [A5] and [A6] into* Table 4.1*.* Adjust with factor in Table 4.2.	Section 4.2.2.	
[B]	**Design Step D2: Identify Hazards**	**Section 4.3**	
[B1]	Chainage of hazard.	Plans.	
[B2]	Description of hazard.	Plans.	
[B3]	Distance from edge of travelled way (left or right).	Plans.	
[B4]	Hazard is within clear zone (yes/no).	Plans.	
[C]	**Design Step D3: Identify Treatment Options**	**Section 4.4**	
[C1]	Assemble appropriate options (examples Section 5).	Site.	
[D]	**Design Step D4: Evaluation of Treatment Options**	**Section 4.5**	
[D1]	Develop treatment options to respond to hazard risk: *Removal* ___________________________________ *Relocation*___________________________________ *Reduction in severity*__________________________ *Shielding*____________________________________ *Change scope or budget*_______________________ *Accept risk*__________________________________	**Section 4.4** **Section 5**	
[D2]	Adopt evaluation method to suit task and jurisdictional requirements. Collate all costs for all treatment options over evaluation period (construction, maintenance, operating). Calculate crash costs for all hazards and treatments in accordance with following risk steps. Undertake qualitative and quantitative evaluation (e.g. benefit/cost in accordance with Austroads 2005)	**Section 4.5**	

ID	Input data	Reference	Result
[E]	**Risk Step R1: Calculate the Frequency of Errant Vehicle Crashes**	**Section 4.6.2**	
[F]	**Risk Step R1a: Determine the Traffic Flow**		
[F1]	AADT Traffic flow (Q).	Statistics.	
[G]	**Risk Step R1b: Determine the Base Run-off-road Frequency (E)**		
[G1]	Divided or undivided road.	Plans.	
[G2]	Adjusted run-off-road frequency (E). *[F1] and [G1] into* Figure 4.11.		
[H]	**Risk Step R1c: Determine the Grade Adjustment Factor (G)**		
[H1]	Grade of carriageway next to hazard (+ or - %).	Plans.	
[H2]	Grade factor (G). *[H1] into* Table 4.6*.*		
[I]	**Risk Step R1d: Determine the Curve Adjustment factor (R)**		
[I1]	Curve radii of carriageway next to hazard (m).	Plans.	
[I2]	Curve factor (R). *[I1] into* Table 4.7*.*		
[J]	**Risk Step R1e: Determine the Probability that a Hazard is Present (P_h)**		
[J1]	Probability that hazard is present (P_h).		1.0
[K]	**Risk Step R1f: Determine the Probability that Errant Vehicles will Reach the Hazard (P_i)**		
[K1]	Distance of hazard from edge line (m).	Plans.	
[K2]	Proportion of errant vehicles that will reach hazard (P_i). *[G1] and [K1] into* Figure 4.12*.*		
[L]	**Risk Step R1g: Calculate the Frequency of Errant Vehicle Crashes**		
[L1]	Frequency of errant vehicle crashes (N). *[G2] x [H2] x [I2] x [J1] x [K2]/278 = [L1].*	[G2] x [H2] X [I2] X [J1] X [K2] /278 = [L1]	__________ x __________ X __________ X _____1.0_____ X __________ /278 = __________
[M]	**Risk Step R2: Determine the Severity Index**	**Section 4.6.3**	
[M1]	Severity index of hazards. *[A3] and [A6] into tables in Appendix E.*		

ID	Input data	Reference	Result
[N]	**Risk Step R3: Calculate Crash Cost for Hazard**	**Section 4.6.4**	
[N1]	Total crashes/year = [F1] x [L1] (for all hazards in group).		
[N2]	Crash costs. *[M1] into jurisdictional equivalent of* Table 4.8		
[O]	**Design Step D5: Rank Treatment Options and Recommend Preferred Action**	**Section 4.7**	
[O1]	Rank options in risk reduction order. Rank options according to benefit/cost. Develop ranking with consideration to qualitative considerations and overall program requirements. Prepare documentation recommending preferred action.		
[P]	**Design Step D6: Design the Roadside Treatments**	**Section 4.8**	
[P1]	Prepare draft road layout design of treatments. Standard drawing available for specific treatments? Select an acceptable product. Prepare and collate detailed designs and specifications.		

Appendix C RTA Method

The Roads and Traffic Authority of New South Wales uses the concept of a hazard corridor to determine the area of interest with respect to roadside hazards.

C.1 Process

The process involves the identification and recording of hazards at the cross-section development stage of design by:

- determining the width of a corridor of interest in which hazards will be identified (the hazard corridor)
- plotting the width of the corridor on the plan.

C.2 Hazard Corridor Width

In order to reduce what could otherwise be an endless hazard identification and risk assessment process, the geographical scope of the risk assessment needs to be specified. This entails defining a hazard corridor within which the risk of all hazards should be calculated. Hazards that lie outside the area will not usually require assessment because the locations are a sufficient distance from the edge of the road that the probability of a collision is relatively small. However, in special circumstances significant hazards outside the hazard corridor may require assessment.

The hazard corridor width is defined as the distance from the edge of the travelled path, sufficient for 80-90% of vehicles to recover following a run-off-road incident and within which hazards should be managed. Vehicles are considered errant when they leave the travelled path onto either the median or the verge.

For this reason, the RTA considers that the hazard corridor applies on both sides of the travelled path and each side must be independently derived according to the road conditions. The implications of this for multi-lane divided roads and for two-lane, two-way roads are illustrated in Figure 4.2 and Figure 4.3 respectively (the clear zone shown in these figures should be taken to represent the hazard corridor).

It should be noted that a vehicle that crosses the centre line or median into the opposite carriageway is an errant vehicle and if the hazard corridor includes at least part of an opposing traffic lane, the RTA considers approaching vehicles to be hazards for the purposes of road design. This is always the case for two-lane, two-way roads, and may be the case for multi-lane divided roads.

C.3 Method

For each road section the base hazard corridor width is determined from Table C 1. Each direction of travel is considered separately.

The table does not include AADT as a determining factor as traffic volume is considered to affect the probability that a vehicle will leave the road but should not affect the distance that an errant vehicle will travel from the road. Factors that affect the width of the hazard corridor are:

- design speed as this influences the distance needed to recover or stop; high-speed vehicles will travel further from the roadway
- road horizontal curvature up to 1000 m radius
- embankment slopes – it can be seen from the table that on non-recoverable fill slopes (≥ 3:1) the width of the fill batter for a 6:1 batter is added to the recovery width because no recovery is possible on such a steep batter, and that an errant vehicle will encroach further on an embankment slope and less on a cutting slope (particularly where the slope is steep).

Table C 1: **Hazard corridor width**

Design speed (km/h)	Curve radius (m)	Hazard corridor width (m)					
		Fill batter			Cut batter		
		*3:1	4:1 – 5:1	6:1 – flat	*3:1	4:1 – 5:1	6:1 – flat
50	50 – 149	Batter width + 7.5	8.3	7.5	7.5	7.5	7.5
	150 – 199	Batter width + 7.0	7.7	7.0	7.0	7.0	7.0
	200 – 299	Batter width + 6.5	7.2	6.5	6.5	6.5	6.5
	300 – 499	Batter width + 6.0	6.6	6.0	6.0	6.0	6.0
	500 – 999	Batter width + 5.5	6.1	5.5	5.5	5.5	5.5
	1000 – Straight	Batter width + 5.0	5.5	5.0	5.0	5.0	5.0
60	90 – 149	Batter width + 7.5	8.3	7.5	7.5	7.5	7.5
	150 – 199	Batter width + 7.0	7.7	7.0	7.0	7.0	7.0
	200 – 299	Batter width + 6.5	7.2	6.5	6.5	6.5	6.5
	300 – 499	Batter width + 6.0	6.6	6.0	6.0	6.0	6.0
	500 – 999	Batter width + 5.5	6.1	5.5	5.5	5.5	5.5
	1000 – Straight	Batter width + 5.0	5.5	5.0	5.0	5.0	5.0
70	150 – 199	Batter width + 9.8	12.8	9.8	7.5	9.0	9.8
	200 – 249	Batter width + 9.1	11.9	9.1	7.0	8.4	9.1
	250 – 349	Batter width + 8.5	11.1	8.5	6.5	7.8	8.5
	350 – 699	Batter width + 7.8	10.2	7.8	6.0	7.2	7.8
	700 – 999	Batter width + 7.2	9.7	7.2	5.5	6.6	7.2
	1000 – Straight	Batter width + 6.5	8.5	6.5	5.0	6.0	6.5
80	240 – 349	Batter width + 9.1	11.9	9.1	7.0	8.4	9.1
	350 – 499	Batter width + 8.5	11.1	8.5	6.5	7.8	8.5
	500 – 899	Batter width + 7.8	10.2	7.8	6.0	7.2	7.8
	900 – 999	Batter width + 7.2	9.4	7.2	5.5	6.6	7.2
	1000 – Straight	Batter width + 6.5	8.5	6.5	5.0	6.0	6.5
90	340 – 349	Batter width + 11.3	15.0	11.3	8.3	9.8	11.3
	350 – 399	Batter width + 10.5	14.0	10.5	7.7	9.1	10.5
	400 – 599	Batter width + 9.8	13.0	9.8	7.2	8.5	9.8
	600 – 999	Batter width + 9.0	12.0	9.0	6.6	7.8	9.0
	1000 – Straight	Batter width + 7.5	10.0	7.5	5.5	6.5	7.5
100	460 – 499	Batter width + 14.0	18.9	14.0	9.1	11.2	11.9
	500 – 699	Batter width + 13.0	17.6	13.0	8.5	10.4	11.1
	700 – 999	Batter width + 12.0	16.2	12.0	7.8	9.6	10.2
	1000 – Straight	Batter width + 10.0	13.5	10.0	6.5	8.0	8.5
110	600 – 699	Batter width + 14.7	19.6	14.7	10.5	12.6	12.6
	700 – 899	Batter width + 13.7	18.2	13.7	9.8	11.7	11.7
	900 – 999	Batter width + 12.6	16.8	12.6	9.0	10.8	10.8
	1000 – Straight	Batter width + 10.5	14.0	10.5	7.5	9.0	9.0

Notes:

** Slopes steeper than 4:1 are not trafficable, are a hazard should be treated as shown for the 3:1 slope.*

The table assumes a flat horizontal surface beyond the toe of the batter - any additional slope beyond the toe should be examined and any further effects to the width calculated and added to the hazard corridor width.

Source: RTA (2008).

Road curvature can affect the lateral distance travelled by an errant vehicle and the extent of lateral run-off-road distance has the mathematical form shown in Equation A1 (TRB 2003):

$$Y = \exp(a + bX) \qquad \text{A1}$$

where

Y = percent exceeding lateral distance X

X = lateral distance

a,b = regression coefficients (a = 4.865, b = -0.262 for two-lane undivided.

Equation A1 is the shape of the curve labelled NCHRP 492 Two lane undivided in Figure C 1.

Road curvature increases roadside run-off-road likelihood. The rate of run-off-road is increased at the outside of a right-hand curve and is greater for tight curves. For tight left-hand curves there is also an increased run-off-road rate on the near side due to over-steering. Since the run-off-road rate is increased, the hazard corridor width is extended and hazards are considered that would otherwise lie outside of the corridor.

The resulting widths in Table C 1 are considered to be a reasonable estimate of the distance required to allow 80-90% of errant vehicles to stop safely or return to the travelled path. This does not show detailed cross-sectional features but considers an average condition for complex slopes.

C.4 Plot the Hazard Corridor

Plotting the hazard corridor on the plans will ensure that roadside furniture and features (e.g. landscaping, sign supports) are designed to be outside the hazard corridor, or adequate protection is provided.

C.5 Background to the Hazard Corridor Width

The clear zone concept was first introduced in the USA in the 1970s. Reports on studies into roadside run-off road crashes stated that an unencumbered corridor with a width of 9 m permits about 80% of the out-of-control vehicles leaving a high-speed roadway to recover (the original dimensions were obtained from incidents at the USA General Motors proving ground). This width did not take into account roadside geometrical factors that may determine the extent of vehicle run-off-road, such as slopes, bends or individual road characteristics. However, a review of accident statistics in the USA showed that these factors do need to be considered in determining recovery width.

The hazard corridor width concept is based on the clear zone width developed by several researchers. The result of research into the relationship between lateral distances travelled before control is regained is shown in Figure C 1.

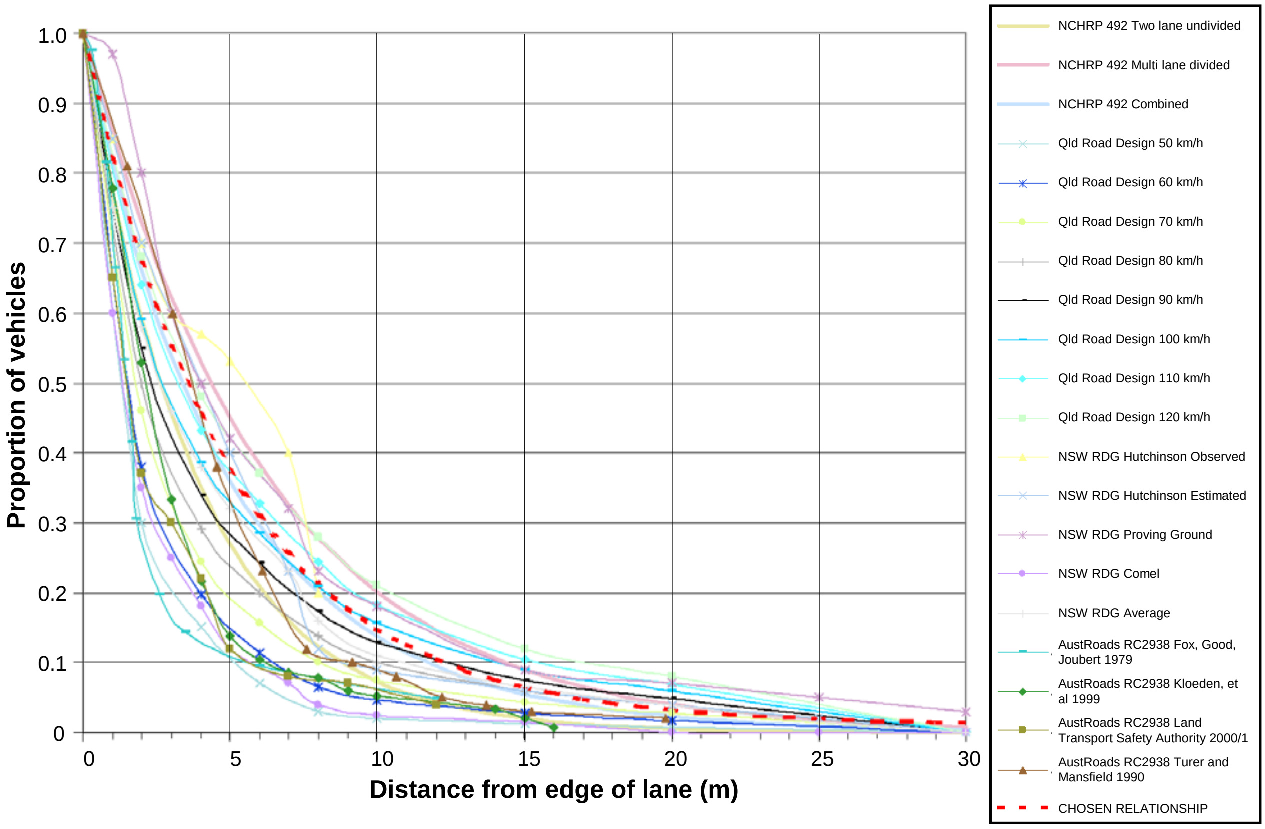
A value of 80-90% was chosen as a satisfactory recovery percentage based on cost-benefit considerations. To design for more than the 85th percentile would require a much wider hazard corridor for a relatively small increase in the number of cars able to recover as shown in Figure C 1.

To design for any less than the 85th percentile is not justified because a small increase in width would provide recovery space for a significant number of additional vehicles.

The principle of a 9 m clear zone width for a relatively flat roadside has been the benchmark for the development of roadside design policy in the USA. Secondary sources suggest that this was based on a study of lateral run-off-road events at the Ford proving ground, but the results of this study do not appear to have been published in the professional literature and are not available for scrutiny. While extensive research has been undertaken to relate other road conditions to this benchmark, there has not been subsequent research into the benchmark itself.

The lateral run-off-road distribution derived from the median run-off-road data implied that there would be little value in clear zones of width less than 8 – 9 m. However, more recent distributions have a form which indicates diminishing safety returns from increasing clear zone width, with more than 85% of the benefit of a 9 m width being obtained in the first 6 m. This implies considerable scope for cost-effective decisions in roadside design. However, quantitative guidance on the crash cost implications of roadside design standards will need to be developed before such trade-offs can be undertaken as part of the design process (McLean 2002).

Figure C 1: Lateral distance travelled before control is regained



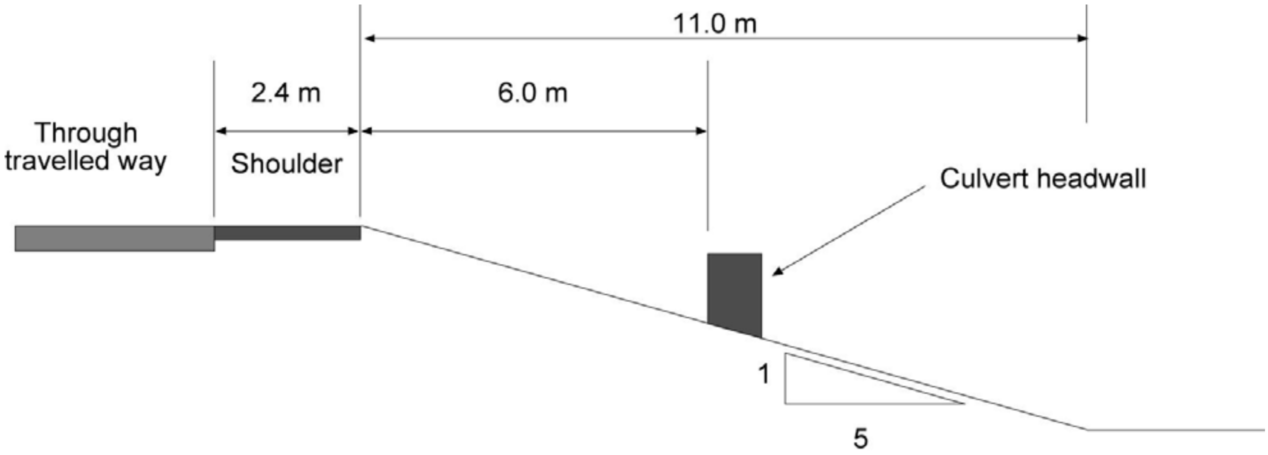
Source: RTA (2008).

Appendix D Examples of Clear Zone Calculations

D.1 Example 1

Design AADT	4000 vpd
Design speed	100 km/h
Alignment	700 m radius horizontal curve
Cross-section	As per Figure D 1

Figure D 1: Example 1 – culvert headwall on outside of horizontal curve



From Table 4.1 the clear zone width (without adjustment for curvature) for an AADT of 4000 vpd, a design speed of 100 km/h and a fill 5:1 batter is 12.0 m. The culvert headwall is situated on the outside of a horizontal curve and therefore an adjustment is required to the clear zone distance. The adjustment for curvature is obtained from Table 4.2; for a 700 m radius horizontal curve a multiplier of 1.2 applies. Therefore the clear zone distance is:

CZ = 12.0 x 1.2 = 14.4 m.

Discussion

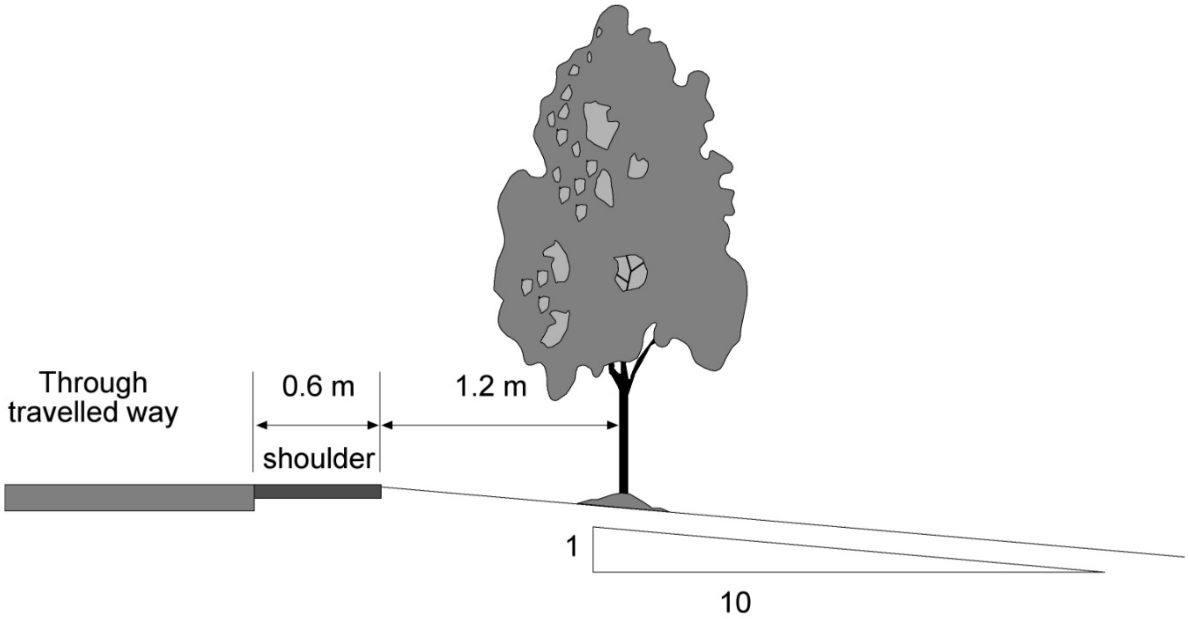
The distance of 8.4 m from the edge of the traffic lane to the hazard is substantially less than the recommended clear zone of 14.4 m. Therefore, if the culvert headwall is greater than 100 mm high and is the only obstruction on an otherwise traversable slope, it should be removed and the culvert end modified to match the 1 on 5 fill batter slope. Bars may be provided across the culvert opening depending on the size of the culvert.

Depending on the size of the culvert and condition of the batter (e.g. it contains rough outcrops of boulders that are a similar hazard to the headwall) then improvement of the batter together with removal of the headwall may be considered. If batter improvement is impracticable an evaluation should be undertaken of the provision of a safety barrier and the do nothing option. A decision to provide a barrier will require an evaluation of the risks associated with the barrier compared to the culvert end wall and batter. A decision to do nothing should take into account the relative risks and benefits of improving this particular culvert compared to other hazardous situations along the road and throughout the road network.

D.2 Example 2

Design AADT	11000 vpd
Design speed	80 km/h
Alignment	300 m radius horizontal curve
Trees	Avenue on the approach to a rural township; trees healthy and on outside of curve; tree removal sensitive in terms of the environment and heritage; tree diameters > 300 mm
Cross-section	As per Figure D 2

Figure D 2: Example 2 – trees close to road



From Table 4.1 the clear zone for an 80 km/h road carrying 11000 vpd with a 10:1 foreslope is 6.5 m. The adjustment factor for a 300 m horizontal curve is 1.4 and therefore the clear zone distance is:

CZ = 6.5 x 1.4 = 9.1 m.

Discussion

As the distance from the edge of traffic lane to the trees is only 1.8 m and the trees are 300 mm in diameter, the trees are a significant hazard to any errant vehicle. If the area has a significant number of off-road crashes and it is not possible to remove the trees and the trees are set back at the same distance, the provision of a safety barrier should be considered to shield all of the trees.

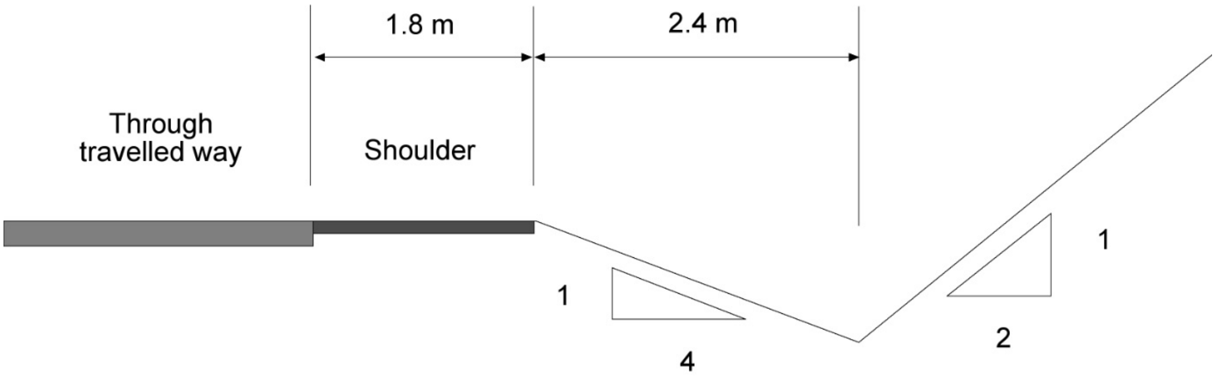
Depending on the results of the analysis this particular tree may not require treatment (e.g. if barrier would be a greater hazard).

Considering that the tree is set back only 1.2 m from the hinge point, a barrier having a dynamic deflection that can be accommodated within the 1.2 m or less will be needed (Section 6.3.7). As the batter is traversable and has a slope of only 10:1 a semi-rigid barrier placed a distance in front of the tree that would accommodate its deflection would be most appropriate. Depending on the volume of van type heavy vehicles using the road, the working width may have to be considered (refer to Section 6.3.17).

D.3 Example 3

Design AADT	800 vpd
Design speed	80 km/h
Alignment	Straight road
Drain cross-section	As per Figure D 3

Figure D 3: Example 3 – foreslope and back slope



From Table 4.1 the clear zone for an 80 km/h road carrying 800 vpd with a 4:1 foreslope is 6.0 m. As the road is straight no adjustment for curvature is necessary and the clear zone is 6.0 m.

Discussion

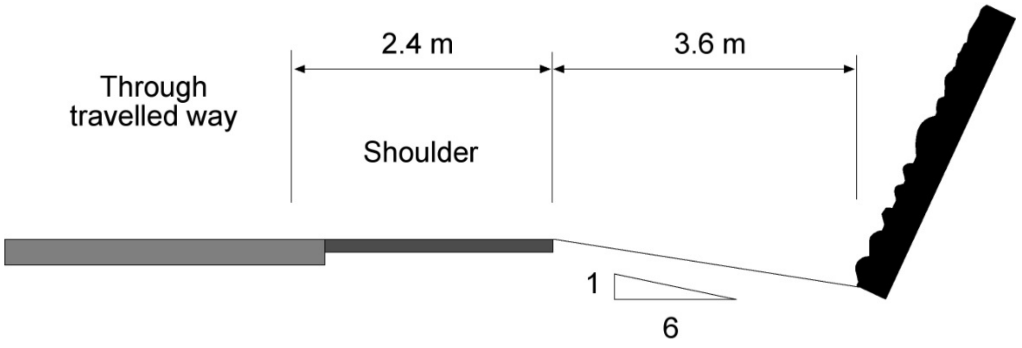
As the bottom of the drain does not have a flat or rounded bottom it is categorised as having abrupt slope changes and the drain does not fall within the preferred cross-section shown in the *Guide to Road Design – Part 3: Geometric Design* (Austroads 2009b) and should desirably be re-shaped to comply or be relocated outside the clear zone if this is practicable.

As the road is straight and the drain bottom and back slope are free of obstacles no treatment is likely to be necessary. A similar cross-section on the outside of a curve would probably be treated because of the increased likelihood of encroachments and the higher angles of impact.

D.4 Example 4

Design AADT	3000 vpd
Design speed	100 km/h
Alignment	Straight
Cross-section	As per Figure D 4, rough cut embankment

Figure D 4: Example 4 – rough cutting within clear zone



The clear zone from Table 4.1 for a 100 km/h road carrying 3000 vpd with a foreslope of 6:1 is 9 m. No adjustment is required for road curvature.

Discussion

As the cut batter is steep and 6.0 m from the edge of the traffic lane and the clear zone required is 9.0 m, the cut batter is a hazard. The cut batter should therefore be treated or shielded. If the material is suitable and filling can be economically used for another planned treatment on the road network the preferred treatment would be to excavate the batter so that it is outside of the clear zone.

If excavation of the batter is not practicable and the batter material is suitable consideration should be given to smoothing the face of the batter (and possibly improving delineation) or providing a safety barrier behind the shoulder. The choice will depend on a risk assessment and evaluation of these options.

Road delineation, particularly on curved sections of road, can be an effective measure at locations that have a significant crash history or potential for run-off-road crashes.

Appendix E Severity Indices Tables

This appendix provides severity indices for use in the assessment of roadside hazards and some treatments that may be implemented to mitigate the hazards, particularly road safety barrier systems. The source of the severity indices is the American Association of State Highway and Transportation Officials publication *Roadside Design Guide* (AASHTO 1996). Whilst the road safety barrier systems presented in the tables may have been superseded or may not accurately reflect systems used in Australia and New Zealand it is considered that the severity indices provide a basis for designers to estimate acceptable severity indices for other products. This process would require knowledge of products and an understanding of their operation.

Table E 1: Suggested severity indices – foreslopes

Object type and characteristics				Object surface (*)	Severity index							
Slope (H:V)	Height (m)	Surface condition			Design speed (km/h)							
					50	60	70	80	90	100	110	120
Foreslope ∞:1	0.0	A	See notes at end of table	F	0.1	0.2	0.2	0.3	0.4	0.5	0.7	0.8
		B		F	0.3	0.4	0.4	0.5	0.6	0.8	1.0	1.1
		C		F	0.4	0.6	0.8	1.0	1.1	1.3	1.5	1.8
		D		F	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
Foreslope 10:1	0.15	A	See notes at end of table	F	0.2	0.3	0.5	0.6	0.7	0.9	1.1	1.2
		B		F	0.4	0.5	0.7	0.8	0.9	1.1	1.3	1.6
		C		F	0.7	0.9	1.1	1.3	1.4	1.6	1.9	2.2
		D		F	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	≥ 0.30	A	See notes at end of table	F	0.4	0.5	0.7	0.8	1.0	1.2	1.4	1.5
		B		F	0.6	0.7	0.9	1.0	1.2	1.4	1.6	1.9
		C		F	0.9	1.1	1.3	1.5	1.7	1.9	2.2	2.5
		D		F	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
Foreslope 8:1	0.15	A	See notes at end of table	F	0.3	0.4	0.6	0.7	0.8	1.0	1.2	1.3
		B		F	0.5	0.6	0.8	0.9	1.0	1.2	1.4	1.7
		C		F	0.8	1.0	1.2	1.4	1.5	1.7	2.0	2.3
		D		F	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	≥ 0.30	A	See notes at end of table	F	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.9
		B		F	0.6	0.8	1.0	1.2	1.4	1.6	1.9	2.2
		C		F	0.9	1.2	1.4	1.7	1.9	2.1	2.5	2.9
		D		F	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
Foreslope 6:1	0.15	A	See notes at end of table	F	0.5	0.8	1.0	1.3	1.5	1.7	1.9	2.0
		B		F	0.7	1.0	1.2	1.5	1.7	1.9	2.1	2.2
		C		F	1.1	1.4	1.7	2.0	2.2	2.4	2.6	2.9
		D		F	2.9	3.4	3.9	4.4	4.9	5.5	5.9	6.3
		E		F	3.3	3.7	4.1	4.6	5.2	5.8	6.4	6.9
	≥ 0.30	A	See notes at end of table	F	0.5	0.8	1.0	1.3	1.6	1.9	2.1	2.2
		B		F	0.7	1.0	1.2	1.5	1.8	2.1	2.3	2.6
		C		F	1.1	1.4	1.7	2.0	2.3	2.6	2.9	3.2
		D		F	3.0	3.8	4.0	4.5	5.0	5.6	6.0	6.4
		E		F	3.4	3.8	4.2	4.7	5.3	5.9	6.5	7.0

Object type and characteristics				Object surface (*)	Severity index							
Slope (H:V)	Height (m)	Surface condition			Design speed (km/h)							
					50	60	70	80	90	100	110	120
Foreslope 4:1	0.15	A	See notes at end of table	F	0.5	0.7	0.9	1.1	1.3	1.5	1.7	2.0
		B		F	0.7	0.9	1.1	1.3	1.5	1.7	2.0	2.3
		C		F	1.0	1.3	1.5	1.8	2.0	2.2	2.6	3.0
		D		F	3.0	3.5	4.0	4.5	5.0	5.6	6.0	6.4
		E		F	3.4	3.8	4.2	4.7	5.3	5.9	6.5	7.0
	0.3	A	See notes at end of table	F	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.5
		B		F	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.9
		C		F	1.7	2.0	2.2	2.5	2.7	2.9	3.2	3.5
		D		F	3.2	3.6	4.0	4.5	5.0	5.6	6.0	6.4
		E		F	3.5	3.9	4.3	4.8	5.4	6.0	6.6	7.1
	≥ 2.0	A	See notes at end of table	F	1.3	1.6	1.8	2.1	2.3	2.5	2.7	2.8
		B		F	1.5	1.8	2.0	2.3	2.5	2.7	2.9	3.2
		C		F	1.9	2.2	2.5	2.8	3.0	3.2	3.5	3.8
		D		F	3.2	3.6	4.0	4.5	5.0	5.6	6.0	6.4
		E		F	3.5	3.9	4.3	4.8	5.4	6.0	6.6	7.1
Foreslope 3:1	0.15	A	See notes at end of table	F	0.7	0.9	1.1	1.3	1.5	1.8	2.0	2.3
		B		F	0.9	1.1	1.3	1.5	1.7	2.0	2.3	2.6
		C		F	1.2	1.5	1.7	2.0	2.2	2.5	2.9	3.3
		D		F	3.2	3.6	4.0	4.5	5.0	5.6	6.0	6.4
		E		F	3.5	3.9	4.3	4.8	5.4	6.0	6.6	7.1
	0.30	A	See notes at end of table	F	1.6	1.8	2.0	2.2	2.4	2.6	2.8	2.9
		B		F	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.3
		C		F	2.1	2.4	2.6	2.9	3.1	3.3	3.6	3.9
		D		F	3.3	3.7	4.1	4.6	5.1	5.7	6.1	6.5
		E		F	3.6	4.0	4.4	4.9	5.5	6.1	6.7	7.2
	2.0	A	See notes at end of table	F	2.0	2.3	2.5	2.8	3.0	3.3	3.5	3.6
		B		F	2.2	2.5	2.7	3.0	3.2	3.5	3.7	4.0
		C		F	2.6	2.9	3.2	3.5	3.7	4.0	4.3	4.6
		D		F	3.4	3.8	4.2	4.7	5.2	5.8	6.2	6.6
		E		F	3.7	4.1	4.5	5.0	5.6	6.2	6.8	7.3
	4.0	A	See notes at end of table	F	2.0	2.3	2.6	2.9	3.1	3.4	3.6	3.9
		B		F	2.2	2.5	2.8	3.1	3.3	3.6	3.9	4.2
		C		F	2.5	2.8	3.2	3.6	3.8	4.1	4.5	4.9
		D		F	3.5	3.9	4.3	4.8	5.3	5.9	6.3	6.7
		E		F	3.8	4.2	4.6	5.1	5.7	6.3	6.9	7.4
	6.0	A	See notes at end of table	F	2.0	2.3	2.6	2.9	3.1	3.5	3.7	4.0
		B		F	2.2	2.5	2.8	3.1	3.3	3.7	4.0	4.3
		C		F	2.5	2.8	3.2	3.6	3.8	4.2	4.6	5.0
		D		F	3.5	3.9	4.3	4.8	5.3	5.9	6.3	6.7
		E		F	3.8	4.2	4.6	5.1	5.7	6.3	6.9	7.4
	8.0	A	See notes at end of table	F	2.0	2.3	2.6	2.9	3.2	3.5	3.8	4.1
		B		F	2.2	2.5	2.8	3.1	3.4	3.7	4.0	4.3
		C		F	2.5	2.8	3.2	3.6	3.9	4.2	4.6	5.0
		D		F	3.5	3.9	4.3	4.8	5.3	5.9	6.3	6.7
		E		F	3.8	4.2	4.6	5.1	5.7	6.3	6.9	7.4
	≥ 10.0	A	See notes at end of table	F	2.0	2.3	2.6	2.9	3.2	3.5	3.9	4.3
		B		F	2.2	2.5	2.8	3.1	3.4	3.7	4.1	4.5
		C		F	2.5	2.8	3.2	3.6	3.9	4.3	4.7	5.1
		D		F	3.5	3.9	4.3	4.8	5.3	5.9	6.3	6.7
		E		F	3.8	4.2	4.3	5.1	5.7	6.3	6.9	7.4

Object type and characteristics				Object surface (*)	Severity index							
Slope (H:V)	Height (m)	Surface condition			Design speed (km/h)							
					50	60	70	80	90	100	110	120
Foreslope 2:1	0.15	A	See notes at end of table	F	0.9	1.2	1.5	1.8	2.0	2.3	2.6	2.9
		B		F	1.1	1.4	1.7	2.0	2.2	2.5	2.9	3.3
		C		F	1.4	1.7	2.1	2.5	2.7	3.1	3.5	3.9
		D		F	3.3	3.7	4.1	4.6	5.1	5.7	6.1	6.5
		E		F	3.6	4.0	4.4	4.9	5.5	6.1	6.7	7.2
	0.30	A	See notes at end of table	F	2.1	2.3	2.5	2.7	2.9	3.1	3.3	3.6
		B		F	2.3	2.5	2.7	2.9	3.1	3.3	3.6	3.9
		C		F	2.6	2.9	3.1	3.4	3.6	3.8	4.2	4.6
		D		F	3.4	3.8	4.2	4.7	5.2	5.8	6.2	6.6
		E		F	3.7	4.1	4.5	5.0	5.6	6.2	6.8	7.3
	2.0	A	See notes at end of table	F	2.9	3.2	3.5	3.8	4.0	4.3	4.5	4.8
		B		F	2.3	2.9	3.4	4.0	4.2	4.5	4.8	5.1
		C		F	2.6	3.2	3.9	4.5	4.7	5.0	5.4	5.8
		D		F	3.5	3.9	4.3	4.8	5.3	5.9	6.3	6.7
		E		F	3.8	4.2	4.6	5.1	5.7	6.3	6.9	7.4
	4.0	A	See notes at end of table	F	3.1	3.4	3.8	4.2	4.4	4.6	4.8	5.1
		B		F	2.5	3.1	3.8	4.4	4.6	4.8	5.1	5.4
		C		F	2.8	3.5	4.2	4.9	5.1	5.3	5.7	6.1
		D		F	3.8	4.1	4.5	4.9	5.4	6.0	6.4	6.8
		E		F	3.9	4.3	4.7	5.2	5.8	6.4	7.0	7.5
	6.0	A	See notes at end of table	F	3.3	3.6	3.9	4.3	4.5	4.7	4.9	5.2
		B		F	3.2	3.6	4.1	4.5	4.7	4.9	5.2	5.5
		C		F	2.9	4.0	4.5	4.9	5.2	5.4	6.1	6.2
		D		F	3.8	4.1	4.5	49	5.4	6.0	6.4	6.8
		E		F	3.9	4.3	4.7	5.2	5.8	6.4	7.0	7.5
	8.0	A	See notes at end of table	F	3.6	3.9	4.1	4.4	4.6	4.8	5.0	5.3
		B		F	3.8	4.1	4.3	4.6	4,8	5.0	5.3	5.6
		C		F	4.1	4.4	4.7	5.0	5.2	5.4	5.8	6.2
		D		F	3.8	4.1	4.5	4.9	5.4	6.0	6.4	6.8
		E		F	3.9	4.3	4.7	5.2	5.8	6.4	7.0	7.5
	10.0	A	See notes at end of table	F	4.1	4.3	4.5	4.7	4.9	5.2	5.4	5.5
		B		F	4.2	4.4	4.6	4.8	5.0	5.3	5.5	5.8
		C		F	4.4	4.7	4.9	5.2	5.4	5.7	6.0	6.3
		D		F	3.8	4.1	4.5	4.9	5.4	6.0	6.4	6.8
		E		F	3.9	4.3	4.7	5.2	5.8	6.4	7.0	7.5
	14.0	A	See notes at end of table	F	4.5	4.7	4.9	5.1	5.3	5.5	5.7	6.0
		B		F	4.6	4.8	5.0	5.2	5.4	5.6	5.9	6.2
		C		F	4.7	5.0	5.2	5.5	5.7	5.9	6.3	6.7
		D		F	3.8	4.1	4.5	4.9	5.4	6.0	6.4	6.8
		E		F	3.9	4.3	4.7	5.2	5.8	6.4	7.0	7.5
	18.0	A	See notes at end of table	F	4.8	5.0	5.2	5.4	5.6	5.8	6.0	6.3
		B		F	4.9	5.1	5.3	5.5	5.7	5.9	6.1	6.4
		C		F	4.9	5.2	5.4	5.7	5.9	6.1	6.4	6.7
		D		F	3.8	4.1	4.5	4.9	5.4	6.0	6.4	6.8
		E		F	3.9	4.3	4.7	5.2	5.8	6.4	7.0	7.5
	22.0	A	See notes at end of table	F	4.9	5.1	5.3	5.5	5.7	5.9	6.1	6.4
		B		F	5.0	5.2	5.4	5.6	5.8	6.0	6.2	6.5
		C		F	5.1	5.3	5.5	5.7	5.9	6.2	6.5	6.8
		D		F	3.8	4.1	4.5	4.9	5.4	6.0	6.4	6.8
		E		F	3.9	4.3	4.7	5.2	5.8	6.4	7.0	7.5

Object type and characteristics				Object surface (*)	Severity index							
Slope (H:V)	Height (m)	Surface condition			Design speed (km/h)							
					50	60	70	80	90	100	110	120
	26.0	A	See notes at end of table	F	4.8	5.1	5.3	5.6	5.8	6.1	6.3	6.4
		B		F	4.9	5.2	5.4	5.7	5.9	6.2	6.4	6.5
		C		F	5.0	5.3	5.5	5.8	6.0	6.3	6.6	6.9
		D		F	3.8	4.1	4.5	4.9	5.4	6.0	6.4	6.8
		E		F	3.9	4.3	4.7	5.2	5.8	6.4	7.0	7.5
	30.0	A	See notes at end of table	F	4.8	5.1	5.3	5.6	5.9	6.2	6.4	6.5
		B		F	4.9	5.2	5.4	5.7	6.0	6.3	6.5	6.6
		C		F	5.0	5.3	5.5	5.8	6.1	6.4	6.6	6.9
		D		F	3.8	4.1	4.5	4.9	5.4	6.0	6.4	6.8
		E		F	3.9	4.3	4.7	5.2	5.8	6.4	7.0	7.5
	≥ 34.0	A	See notes at end of table	F	4.8	5.1	5.3	5.6	5.9	6.2	6.4	6.7
		B		F	4.9	5.3	5.4	5.7	6.0	6.3	6.5	6.8
		C		F	5.0	5.3	5.5	5.8	6.1	6.4	6.6	6.9
		D		F	3.8	4.1	4.5	4.9	5.4	6.0	6.6	7.3
		E		F	3.9	4.3	4.7	5.2	5.8	6.4	7.0	7.5
Foreslope 1 ½ : 1	0.15	A	See notes at end of table	F	0.9	1.3	1.7	2.2	2.4	2.7	3.0	3.3
		B		F	1.1	1.5	1.9	2.4	2.6	2.9	3.3	3.7
		C		F	1.4	1.9	2.4	2.9	3.1	3.5	3.9	4.3
		D		F	3.3	3.8	4.3	4.8	5.3	5.9	6.3	6.7
		E		F	3.7	4.1	4.5	5.0	5.6	6.2	6.8	7.3
	0.30	A	See notes at end of table	F	2.4	2.6	2.8	3.0	3.2	3.5	3.7	4.0
		B		F	2.6	2.8	3.0	3.2	3.4	3.7	4.0	4.3
		C		F	2.9	3.2	3.4	3.7	3.9	4.2	4.6	5.0
		D		F	3.3	3.8	4.3	4.8	5.3	5.9	6.4	6.9
		E		F	3.7	4.1	4.5	5.0	5.6	6.2	6.9	7.6
	2.0	A	See notes at end of table	F	3.3	3.6	3.9	4.2	4.5	4.8	5.0	5.3
		B		F	3.2	3.5	3.7	4.0	4.4	4.8	5.2	5.6
		C		F	3.6	3.9	4.2	4.5	4.9	5.3	5.8	6.3
		D		F	3.4	3.9	4.4	4.9	5.4	6.0	6.5	7.0
		E		F	3.7	4.1	4.5	5.0	5.6	6.2	6.9	7.6
	4.0	A	See notes at end of table	F	3.8	4.1	4.4	4.7	4.9	5.2	5.4	5.7
		B		F	3.8	4.1	4.5	4.9	5.4	5.9	6.2	6.5
		C		F	4.8	5.0	5.2	5.4	5.8	6.3	6.8	7.3
		D		F	3.8	4.1	4.5	4.9	5.4	6.0	6.5	7.0
		E		F	3.8	4.2	4.6	5.1	5.7	6.3	7.0	7.7
	6.0	A	See notes at end of table	F	4.1	4.4	4.7	5.0	5.2	5.5	5.7	6.0
		B		F	4.7	4.4	4.7	5.5	5.9	6.3	6.6	7.0
		C		F	5.3	5.4	5.7	5.9	6.2	6.7	7.2	7.6
		D		F	3.9	4.2	4.6	5.0	5.5	6.0	6.6	7.2
		E		F	3.9	4.3	4.7	5.1	5.8	6.4	7.1	7.8
	8.0	A	See notes at end of table	F	4.3	4.6	4.9	5.2	5.4	5.7	5.9	6.2
		B		F	5.5	5.6	5.8	5.9	6.3	6.6	7.0	7.4
		C		F	5.7	5.9	6.1	6.3	6.6	7.0	7.5	8.0
		D		F	3.9	4.2	4.6	5.0	5.5	6.0	6.6	7.3
		E		F	3.9	4.3	4.7	5.2	5.8	6.4	7.1	7.8
	10.0	A	See notes at end of table	F	4.9	5.2	5.4	5.7	6.0	6.3	6.6	6.9
		B		F	6.4	6.5	6.7	6.8	7.2	7.6	7.8	8.1
		C		F	6.8	6.9	7.1	7.2	7.6	8.0	8.2	8.5
		D		F	4.0	4.3	4.7	5.1	5.6	6.1	6.7	7.4
		E		F	4.0	4.4	4.8	5.3	5.9	6.5	7.2	7.9

Object type and characteristics				Object surface (*)	Severity index							
Slope (H:V)	Height (m)	Surface condition			Design speed (km/h)							
					50	60	70	80	90	100	110	120
	14.0	A	See notes at end of table	F	5.4	5.7	5.9	6.2	6.6	6.9	7.2	7.5
		B		F	7.1	7.2	7.4	7.5	7.9	8.2	8.5	8.8
		C		F	7.5	7.6	7.8	7.9	8.2	8.5	8.8	9.1
		D		F	4.0	4.3	4.7	5.1	5.6	6.1	6.7	7.4
		E		F	4.0	4.4	4.8	5.3	5.9	6.5	7.2	7.9
	18.0	A	See notes at end of table	F	5.8	6.1	6.4	6.7	7.1	7.4	7.7	8.0
		B		F	7.6	7.7	7.9	8.0	8.4	8.7	9.0	9.3
		C		F	7.9	8.0	8.2	8.3	8.6	8.9	9.2	9.5
		D		F	4.0	4.3	4.7	5.1	5.6	6.1	6.7	7.4
		E		F	4.0	4.4	4.8	5.3	5.9	6.5	7.2	7.9
	22.0	A	See notes at end of table	F	6.2	6.5	6.8	7.1	7.4	7.7	8.0	8.3
		B		F	7.7	7.9	8.1	8.3	8.6	8.9	9.1	9.2
		C		F	8.0	8.2	8.4	8.6	8.8	9.1	9.3	9.4
		D		F	4.0	4.3	4.7	5.1	5.6	6.1	6.7	7.4
		E		F	4.2	4.5	4.9	5.3	5.9	6.5	7.2	7.9
	26.0	A	See notes at end of table	F	6.3	6.6	6.9	7.2	7.5	7.8	8.1	8.4
		B		F	7.9	8.1	8.3	8.5	8.8	9.1	9.3	9.6
		C		F	8.0	8.3	8.5	8.8	9.0	9.2	9.4	9.7
		D		F	4.1	4.4	4.8	5.2	5.6	6.1	6.7	7.4
		E		F	4.2	4.5	4.9	5.3	5.9	6.5	7.2	7.9
	30.0	A	See notes at end of table	F	6.6	6.9	7.1	7.4	7.7	8.0	8.3	8.6
		B		F	7.8	8.1	8.3	8.6	8.8	9.1	9.4	9.7
		C		F	8.0	8.3	8.5	8.8	9.0	9.2	9.4	9.7
		D		F	4.1	4.4	4.8	5.2	5.5	6.1	6.7	7.4
		E		F	4.2	4.5	4.9	5.3	5.9	6.5	7.2	7.9
	34.0	A	See notes at end of table	F	6.8	7.1	7.3	7.6	7.8	8.1	8.4	8.7
		B		F	7.9	8.2	8.4	8.7	8.9	9.2	9.4	9.7
		C		F	8.1	8.4	8.6	8.9	9.0	9.2	9.4	9.7
		D		F	4.1	4.4	4.8	5.2	5.6	6.1	6.7	7.4
		E		F	4.2	4.5	4.9	5.3	5.9	6.5	7.2	7.9
	≥ 38.0	A	See notes at end of table	F	6.9	7.2	7.4	7.7	7.9	8.2	8.5	8.8
		B		F	8.0	8.3	8.5	8.8	9.0	9.3	9.5	9.8
		C		F	8.3	8.5	8.7	8.9	9.1	9.3	9.5	9.8
		D		F	4.1	4.4	4.8	5.2	5.6	6.1	6.7	7.4
		E		F	4.2	4.5	4.9	5.3	5.9	6.5	7.2	7.9

**S = Approach Side, C = Corner, F = Traffic Face, A = S, C, and F.*

Notes:

A. *Smooth and firm all seasons.*

B. *Smooth but subject to deep rutting by errant vehicles half of the year.*

C. *Shallow gullies (I00 to 200 mm deep), scattered small boulders (under 225 mm projections), scattered small trees (diameters 75 to 100 mm), or structurally substantial woody brush. Features spaced so that nearly all encroaching vehicles will encounter them.*

D. *Medium gullies (approximately 250 mm deep), boulders or riprap (projecting approximately 300 mm), or medium trees (diameters 175 to 225 mm). Features spaced so that they will be encountered by all encroaching vehicles. It is assumed that density of features will preclude deep penetration of roadside. If this assumption is not valid, severity indices for high, steep slopes may be considerably higher than values shown.*

E. *Deep gullies (over 0.5 m deep), large boulders or heavy riprap (over 450 mm projecting), large trees (diameters over 350 mm). Features spaced so that they will be encountered by all encroaching vehicles. It is assumed that density of features will preclude deep penetration of roadside. If this assumption is not valid, severity indices for high, steep slopes may be considerably higher than values shown.*

Table E 2: Suggested severity indices – foreslope – vertical with and without water present

Object type and characteristics			Object surface (*)	Severity index, SI							
Slope (H:V)	Height (m)	Water depth (m)		Design speed (km/h)							
				50	60	70	80	90	100	110	120
Foreslope vertical	0.0	0	F	0.1	0.2	0.2	0.3	0.4	0.5	0.7	0.8
		1	F	2.6	2.7	2.9	3.0	3.2	3.4	3.6	3.7
		2	F	4.4	4.7	4.9	5.2	5.4	5.7	5.9	6.2
		4	F	6.2	6.4	6.6	6.8	7.0	7.2	7.4	7.7
		≥ 6	F	7.9	8.1	8.3	8.5	8.7	8.8	9.0	9.1
	0.3	0	F	2.6	2.9	3.1	3.4	3.6	3.9	4.1	4.4
		1	F	3.2	3.4	3.6	3.8	4.0	4.2	4.4	4.7
		2	F	4.6	4.9	5.2	5.5	5.9	6.2	6.6	7.0
		4	F	6.3	6.6	6.9	7.2	7.4	7.7	7.9	8.2
		≥ 6	F	8.2	8.3	8.5	8.6	8.8	9.0	9.2	9.3
	2.0	0	F	3.8	4.1	4.3	4.6	4.8	5.1	5.3	5.6
		1	F	4.4	4.6	4.8	5.0	5.2	5.4	5.6	5.7
		2	F	6.7	6.8	7.0	7.1	7.3	7.5	7.7	7.8
		4	F	7.6	7.7	7.9	8.0	8.2	8.4	8.6	8.7
		≥ 6	F	8.4	8.5	8.7	8.8	9.0	9.2	9.4	9.5
	4.0	0	F	5.7	5.8	5.8	5.9	6.1	6.3	6.5	6.6
		1	F	5.7	5.9	6.1	6.3	6.5	6.7	6.9	7.0
		2	F	7.4	7.5	7.7	7.8	8.0	8.2	8.4	8.5
		4	F	8.0	8.1	8.3	8.4	8.6	8.8	9.0	9.1
		≥ 6	F	8.6	8.7	8.9	9.0	9.2	9.4	9.6	9.7
	6.0	0	F	6.6	6.7	6.8	6.9	7.0	7.2	7.4	7.5
		1	F	6.8	6.9	7.1	7.3	7.4	7.6	7.8	7.9
		2	F	7.8	7.9	8.1	8.2	8.4	8.6	8.8	8.9
		4	F	8.2	8.3	8.5	8.7	8.9	9.1	9.3	9.4
		≥ 6	F	8.7	8.8	9.0	9.1	9.3	9.5	9.7	9.8
	8.0	0	F	7.4	7.5	7.7	7.8	7.9	8.0	8.2	8.3
		1	F	7.8	7.9	8.1	8.2	8.3	8.4	8.6	8.7
		2	F	8.1	8.2	8.4	8.5	8.7	8.9	9.1	9.2
		4	F	8.3	8.5	8.7	8.9	9.1	9.3	9.5	9.6
		≥ 6	F	8.8	8.9	9.1	9.2	9.4	9.6	9.8	9.9
	10.0	0	F	8.6	8.8	9.0	9.2	9.2	9.2	9.3	9.3
		1	F	8.7	8.9	9.1	9.3	9.4	9.4	9.6	9.7
		2	F	9.2	9.3	9.3	9.4	9.5	9.6	9.8	9.9
		4	F	9.5	9.6	9.6	9.7	9.8	9.8	9.9	9.9
		≥ 6	F	9.7	9.8	9.8	9.9	10.0	10.0	10.0	10.0
	14.0	0	F	9.5	9.6	9.6	9.7	9.8	9.8	9.8	9.8
		1	F	9.6	9.7	9.7	9.8	9.8	9.8	9.9	9.9
		2	F	9.6	9.7	9.7	9.8	9.9	9.9	10.0	10.0
		4	F	9.8	9.9	9.9	10.0	10.0	10.0	10.0	10.0
		≥ 6	F	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
	18.0	0	F	9.9	9.9	9.9	9.9	9.9	9.9	10.0	10.0
		1	F	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
		2	F	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
		4	F	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
		≥ 6	F	10.0	10.0	10.0	10.0	10.0	10,0	10.0	10.0

Object type and characteristics			Object surface (*)	Severity index, SI							
Slope (H:V)	Height (m)	Water depth (m)		Design speed (km/h)							
				50	60	70	80	90	100	110	120
	22.0	0	F	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
		1	F	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
		2	F	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
		4	F	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
		≥ 6	F	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0

**S = Approach Side, C = Corner, F = Traffic Face, A = S, C, and F.*

Table E 3: Suggested severity indices – backslopes

Object type and characteristics				Object surface (*)	Severity index, SI							
Slope (H:V)	Height (m)	Surface condition			Design speed (km/h)							
					50	60	70	80	90	100	110	120
Backslope 10:1	0.15	A	See notes at end of Table	F	0.1	0.1	0.1	0.2	0.3	0.4	0.6	0.7
		B		F	0.2	0.3	0.3	0.4	0.5	0.7	0.9	1.0
		C		F	0.6	0.7	0.9	1.0	1.1	1.3	1.5	1.8
		D		F	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	≥ 0.3	A	See notes at end of Table	F	0.1	0.1	0.1	0.2	0.3	0.3	0.5	0.6
		B		F	0.1	0.1	0.3	0.4	0.5	0.6	0.8	0.9
		C		F	0.6	0.7	0.9	1.0	1.1	1.3	1.5	1.8
		D		F	2.6	3.2	3.9	4.5	5.1	5.7	6.3	7.0
		E		F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
Backslope 8:1	0.15	A	See notes at end of Table	F	0.1	0.1	0.2	0.3	0.4	0.4	0.6	0.7
		B		F	0.1	0.2	0.4	0.5	0.6	0.7	0.9	1.0
		C		F	0.6	0.7	0.9	1.0	1.1	1.3	1.5	1.8
		D		F	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	≥ 0.3	A	See notes at end of Table	F	0.1	0.1	0.1	0.2	0.3	0.3	0.5	0.6
		B		F	0.1	0.2	0.2	0.3	0.4	0.6	0.8	0.9
		C		F	0.6	0.7	0.9	1.0	1.1	1.3	1.5	1.8
		D		F	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
Backslope 6:1	0.15	A	See notes at end of Table	F	0.1	0.1	0.3	0.4	0.5	0.5	1.7	0.8
		B		F	0.3	0.4	0.4	0.5	0.6	0.8	1.0	1.1
		C		F	0.6	0.7	0.9	1.0	1.1	1.3	1.5	1.8
		D		F	2.8	3.6	3.8	4.3	4.8	5.4	5.9	6.4
		E		F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	≥ 0.5	A	See notes at end of Table	F	0.1	0.1	0.1	0.2	0.3	0.3	0.5	0.6
		B		F	0.1	0.2	0.4	0.5	0.5	0.6	0.8	0.9
		C		F	0.6	0.7	0.9	1.0	1.1	1.3	1.5	1.8
		D		F	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
Backslope 4:1	≥ 0.15	A	See notes at end of Table	F	0.1	0.1	0.3	0.4	0.5	0.6	0.8	0.9
		B		F	0.4	0.5	0.5	0.6	0.7	0.9	1.1	1.2
		C		F	0.7	0.8	1.0	1.1	1.3	1.4	1.6	1.7
		D		F	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0

Object type and characteristics				Object surface (*)	Severity index, SI							
Slope (H:V)	Height (m)	Surface condition			Design speed (km/h)							
					50	60	70	80	90	100	110	120
Backslope 3:1	0.15	A	See notes at end of Table	F	0.2	0.3	0.5	0.6	0.7	0.7	0.9	1.0
		B		F	0.4	0.5	0.7	0.8	0.9	1.1	1.3	1.4
		C		F	0.8	0.9	1.1	1.2	1.4	1.6	1.8	1.9
		D		F	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	≥ 1.0	A	See notes at end of Table	F	0.3	0.4	0.6	0.7	0.9	1.2	1.3	1.4
		B		F	0.7	0.8	1.0	1.1	1.3	1.5	1.7	1.8
		C		F	1.3	1.4	1.6	1.7	1.9	2.1	2.3	2.4
		D		F	2.9	3.4	3.9	4.4	4.9	5.5	6.0	6.5
		E		F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
Backslope 2:1	0.15	A	See notes at end of Table	F	0.4	0.5	0.7	0.8	1.0	1.2	1.4	1.7
		B		F	0.7	0.8	1.0	1.1	1.3	1.5	1.7	2.0
		C		F	1.0	1.1	1.3	1.4	1.6	1.9	2.2	2.5
		D		F	2.9	3.4	3.9	4.4	4.9	5.5	6.0	6.5
		E		F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.3	A	See notes at end of Table	F	0.5	0.6	0.8	0.9	1.1	1.3	1.6	1.9
		B		F	0.9	1.0	1.2	1.3	1.4	1.6	1.9	2.2
		C		F	1.4	1.5	1.7	1.8	1.9	2.1	2.3	2.6
		D		F	3.0	3.5	4.0	4.5	5.0	5.6	6.1	6.6
		E		F	3.3	3.7	4.1	4.6	5.2	5.8	6.4	7.1
	0.6	A	See notes at end of Table	F	0.7	0.8	1.0	1.1	1.3	1.5	1.8	2.1
		B		F	1.1	1.2	1.4	1.5	1.7	1.9	2.1	2.4
		C		F	1.9	2.0	2.2	2.3	2.4	2.6	2.8	3.1
		D		F	3.0	3.5	4.0	4.5	5.0	5.6	6.1	6.6
		E		F	3.3	3.7	4.1	4.6	5.2	5.8	6.4	7.1
	≥ 1.2	A	See notes at end of Table	F	0.8	0.9	1.1	1.2	1.5	1.8	2.1	2.4
		B		F	1.2	1.3	1.5	1.6	1.8	2.1	2.3	2.6
		C		F	2.0	2.1	2.3	2.4	2.5	2.7	2.9	3.2
		D		F	3.0	3.5	4.0	4.5	5.0	5.6	6.1	6.6
		E		F	3.3	3.7	4.1	4.6	5.2	5.8	6.4	7.1
Backslope 1½:1	0.15	A	See notes at end of Table	F	0.3	0.6	0.8	1.1	1.4	1.8	2.2	2.6
		B		F	0.6	0.9	1.1	1.4	1.7	2.1	2.5	2.9
		C		F	0.9	1.2	1.4	1.7	2.1	2.5	3.0	3.5
		D		F	2.9	3.4	3.9	4.4	4.9	5.5	6.0	6.5
		E		F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	≥ 0.3	A	See notes at end of Table	F	0.5	0.8	1.0	1.3	1.6	2.0	2.6	3.1
		B		F	0.9	1.2	1.4	1.7	1.9	2.3	2.9	3.4
		C		F	1.4	1.7	1.9	2.2	2.4	2.8	3.3	3.8
		D		F	3.0	3.5	4.0	4.5	5.0	5.6	6.1	6.6
		E		F	3.3	3.7	4.1	4.6	5.2	5.8	6.4	7.1
	0.6	A	See notes at end of Table	F	0.9	1.1	1.3	1.5	1.8	2.2	2.7	3.2
		B		F	1.3	1.5	1.7	1.9	2.2	2.6	3.1	3.6
		C		F	2.1	2.3	2.5	2.7	2.9	3.2	3.8	4.3
		D		F	3.0	3.5	4.0	4.5	5.0	5.6	6.1	6.6
		E		F	3.3	3.7	4.1	4.6	5.2	5.8	6.4	7.1
	≥ 1.2	A	See notes at end of Table	F	1.0	1.2	1.4	1.6	2.0	2.4	2.8	3.2
		B		F	1.4	1.6	1.8	2.0	2.3	2.7	3.2	3.7
		C		F	2.2	2.4	2.6	2.8	3.0	3.4	3.9	4.4
		D		F	3.1	3.6	4.1	4.6	5.1	5.7	6.2	6.7
		E		F	3.3	3.7	4.1	4.6	5.2	5.8	6.4	7.1

Object type and characteristics				Object surface (*)	Severity index, SI							
Slope (H:V)	Height (m)	Surface condition			Design speed (km/h)							
					50	60	70	80	90	100	110	120
Backslope 1:1	0.15	A	See notes at end of Table	F	0.4	0.7	1.0	1.3	1.7	2.2	2.8	3.3
		B		F	0.7	1.0	1.3	1.6	2.0	2.5	3.1	3.6
		C		F	1.0	1.3	1.6	1.9	2.4	2.9	3.5	4.2
		D		F	2.9	3.4	3.9	4.4	4.9	5.5	6.0	6.5
		E		F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.3	A	See notes at end of Table	F	0.7	1.0	1.3	1.6	2.0	2.4	3.1	3.8
		B		F	1.1	1.4	1.7	2.0	2.3	2.7	3.4	4.1
		C		F	1.6	1.9	2.2	2.5	2.8	3.2	3.8	4.5
		D		F	3.0	3.5	4.0	4.5	5.0	5.6	6.1	6.6
		E		F	3.3	3.7	4.1	4.6	5.1	5.8	6.4	7.1
	0.6	A	See notes at end of Table	F	1.0	1.3	1.5	1.8	2.2	2.6	3.3	4.0
		B		F	1.4	1.7	1.9	2.2	2.6	3.0	3.6	4.1
		C		F	2.2	2.5	2.7	3.0	3.2	3.6	4.2	4.9
		D		F	3.0	3.5	4.0	4.5	5.0	5.6	6.1	6.6
		E		F	3.3	3.7	4.1	4.6	5.2	5.8	6.4	7.1
	≥ 1.2	A	See notes at end of Table	F	1.1	1.4	1.6	1.9	2.3	2.8	3.4	3.9
		B		F	1.5	1.8	2.0	2.3	2.7	3.1	3.7	4.2
		C		F	2.3	2.6	2.8	3.1	3.4	3.8	4.4	4.9
		D		F	3.1	3.6	4.1	4.6	5.1	5.7	6.2	6.7
		E		F	3.3	3.7	4.1	4.6	5.2	5.8	6.4	7.1
Backslope vertical	0.15	A	See notes at end of Table	F	0.5	0.8	1.1	1.4	1.9	2.4	3.0	3.7
		B		F	0.8	1.1	1.4	1.7	2.2	2.7	3.3	4.0
		C		F	1.1	1.4	1.7	2.0	2.5	3.1	3.8	4.5
		D		F	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.3	A	See notes at end of Table	F	0.7	1.0	1.3	1.6	2.0	2.5	3.2	3.9
		B		F	1.1	1.4	1.7	2.0	2.4	2.8	3.5	4.2
		C		F	1.6	1.9	2.2	2.5	2.9	3.3	3.9	4.6
		D		F	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.6	A	See notes at end of Table	F	0.7	1.0	1.3	1.6	2.0	2.4	3.0	3.7
		B		F	1.1	1.4	1.7	2.0	2.3	2.7	3.3	4.0
		C		F	1.6	1.9	2.2	2.5	2.8	3.2	3.8	4.3
		D		F	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	≥1:0	A	See notes at end of Table	F	0.6	0.9	1.2	1.5	1.9	2.3	2.9	3.6
		B		F	1.0	1.3	1.6	1.9	2.2	2.6	3.2	3.9
		C		F	1.5	1.8	2.1	2.4	2.7	3.1	3.7	4.2
		D		F	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		F	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0

**S = Approach Side, C = Corner, F = Traffic Face, A = S, C, and F.*

Notes:

A. Smooth and firm all seasons.

B. Smooth but subject to deep rutting by errant vehicles half of the year.

C. Shallow gullies (I00 to 200 mm deep), scattered small boulders (under 225 mm projections), scattered small trees (diameters 75 to 100 mm), or structurally substantial woody brush. Features spaced so that nearly all encroaching vehicles will encounter them.

D. *Medium gullies (approximately 250 mm deep), boulders or riprap (projecting approximately 300 mm), or medium trees (diameters 175 to 225 mm). Features spaced so that they will be encountered by all encroaching vehicles. It is assumed that density of features will preclude deep penetration of roadside. If this assumption is not valid, severity indices for high, steep slopes may be considerably higher than values shown.*

E. *Deep gullies (over 0.5 m deep), large boulders or heavy riprap (over 450 mm projecting), large trees (diameters over 350 mm). Features spaced so that they will be encountered by all encroaching vehicles. It is assumed that density of features will preclude deep penetration of roadside. If this assumption is not valid, severity indices for high, steep slopes may be considerably higher than values shown.*

Table E 4: Suggested severity indices – parallel ditches

Object type and characteristics			Object surface (*)	Severity index, SI							
Foreslope	Backslope	Depth (m)		Design speed (km/h)							
				50	60	70	80	90	100	110	120
2:1 Slope	2:1 Slope	0.15	F	1.2	1.5	1.7	2.0	2.4	2.8	3.4	3.9
		0.30	F	1.7	1.8	2.0	2.1	2.5	2.9	3.5	4.0
		0.60	F	1.9	2.0	2.2	2.3	2.7	3.1	3.6	4.1
		1.00	F	2.0	2.1	2.3	2.4	2.7	3.1	3.6	4.1
		1.20	F	2.1	2.2	2.4	2.5	2.8	3.2	3.7	4.2
	3:1 Slope	0.15	F	1.1	1.4	1.6	1.9	2.2	2.6	3.1	3.6
		0.30	F	1.5	1.7	1.9	2.1	2.4	2.8	3.2	3.6
		0.60	F	1.8	1.9	2.1	2.2	2.5	2.9	3.4	3.9
		1.00	F	1.9	2.0	2.2	2.3	2.5	2.9	3.5	4.0
		1.20	F	2.0	2.1	2.3	2.4	2.6	3.0	3.6	4.1
3:1 Slope	2:1 Slope	0.15	F	1.2	1.5	1.7	2.0	2.4	2.8	3.4	3.9
		0.30	F	1.6	1.7	1.9	2.0	2.4	2.8	3.4	3.9
		0.60	F	1.9	2.0	2.0	2.1	2.5	2.9	3.4	3.9
		1.00	F	2.0	2.1	2.1	2.2	2.5	2.9	3.4	3.9
		1.20	F	2.1	2.2	2.2	2.3	2.6	3.0	3.4	3.8
	3:1 Slope	0.15	F	1.1	1.4	1.6	1.9	2.2	2.6	3.1	3.6
		0.30	F	1.4	1.6	1.8	2.0	2.3	2.7	3.1	3.5
		0.60	F	1.7	1.8	2.0	2.1	2.3	2.7	3.1	3.5
		1.00	F	1.8	1.9	2.1	2.2	2.4	2.7	3.1	3.5
		1.20	F	2.0	2.1	2.1	2.2	2.4	2.8	3.2	3.6
	4:1 Slope	0.15	F	1.1	1.3	1.5	1.7	1.9	2.3	2.7	3.1
		0.30	F	1.3	1.5	1.7	1.9	2.1	2.4	2.8	3.2
		0.60	F	1.6	1.7	1.9	2.0	2.2	2.4	2.8	3.2
		1.00	F	1.9	2.0	2.0	2.1	2.2	2.5	2.9	3.3
		1.20	F	1.8	1.9	2.1	2.2	2.3	2.5	2.9	3.3
4:1 Slope	2:1 Slope	0.15	F	1.1	1.4	1.6	1.9	2.3	2.7	3.2	3.7
		0.30	F	1.1	1.4	1.6	1.9	2.3	2.7	3.2	3.7
		0.60	F	1.2	1.5	1.7	2.0	2.3	2.7	3.2	3.7
		1.00	F	1.2	1.5	1.7	2.0	2.3	2.7	3.1	3.5
		1.20	F	1.2	1.5	1.7	2.0	2.3	2.7	3.1	3.5

Object type and characteristics			Object surface (*)	Severity index, SI							
Foreslope	Backslope	Depth (m)		Design speed (km/h)							
				50	60	70	80	90	100	110	120
	3:1 Slope	0.15	F	1.0	1.2	1.4	1.6	1.9	2.3	2.7	3.1
		0.30	F	1.1	1.3	1.5	1.7	1.9	2.3	2.7	3.1
		0.60	F	1.0	1.3	1.5	1.8	2.0	2.3	2.7	3.1
		1.00	F	1.1	1.4	1.6	1.9	2.1	2.3	2.7	3.1
		1.20	F	1.1	1.4	1.7	2.0	2.1	2.3	2.7	3.1
	4:1 Slope	0.15	F	0.9	1.1	1.3	1.5	1.7	2.0	2.3	2.6
		0.30	F	1.0	1.2	1.4	1.6	1.8	2.1	2.3	2.6
		0.60	F	1.1	1.3	1.5	1.7	1.9	2.2	2.4	2.5
		1.00	F	1.0	1.3	1.5	1.8	2.0	2.2	2.4	2.7
		1.20	F	1.1	1.4	1.6	1.9	2.1	2.3	2.5	2.6
6:1 Slope	2:1 Slope	0.15	F	0.8	1.1	1.3	1.6	2.0	2.4	2.9	3.4
		0.30	F	0.8	1.1	1.3	1.6	2.0	2.4	2.9	3.4
		0.60	F	0.7	1.0	1.2	1.5	1.9	2.3	2.7	3.1
		1.00	F	0.6	0.9	1.1	1.4	1.8	2.2	2.5	2.8
		1.20	F	0.6	0.9	1.1	1.4	1.8	2.2	2.4	2.7
	3:1 Slope	0.15	F	0.7	0.9	1.1	1.3	1.6	1.9	2.2	2.5
		0.30	F	0.7	0.9	1.1	1.3	1.6	1.9	2.2	2.5
		0.60	F	0.7	0.9	1.1	1.3	1.6	1.9	2.2	2.5
		1.00	F	0.5	0.8	1.0	1.3	1.6	1.9	2.1	2.4
		1.20	F	0.5	0.8	1.0	1.3	1.6	1.9	2.1	2.4
	4:1 Slope	0.15	F	0.5	0.7	0.9	1.1	1.3	1.6	1.9	2.2
		0.30	F	0.4	0.7	0.9	1.2	1.4	1.7	1.9	2.2
		0.60	F	0.6	0.8	1.0	1.2	1.4	1.7	1.9	2.2
		1.00	F	0.6	0.8	1.0	1.2	1.5	1.8	2.0	2.1
		1.20	F	0.6	0.8	1.0	1.2	1.5	1.8	2.0	2.1
	6:1 Slope	0.15	F	0.5	0.6	0.8	0.9	1.1	1.3	1.5	1.6
		0.30	F	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.7
		0.60	F	0.6	0.7	0.9	1.0	1.2	1.5	1.7	2.0
		1.00	F	0.5	0.7	0.9	1.1	1.3	1.6	1.8	2.1
		1.20	F	0.4	0.7	0.9	1.2	1.4	1.6	1.9	2.2

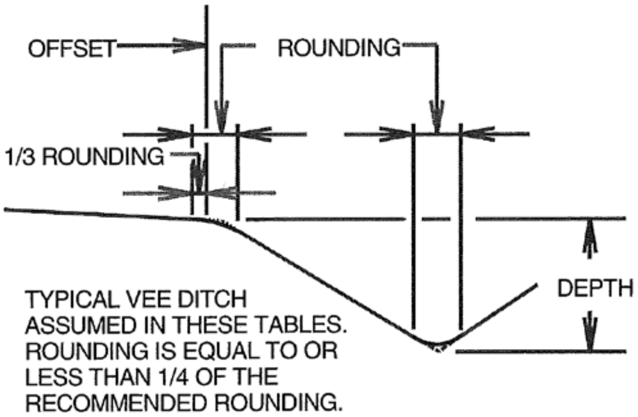
**S = Approach Side, C = Corner, F = Traffic Face, A = S, C, and F.*

Notes:

For ditch configurations where the ditch bottom is 2.5 m wide or wider the foreslope and backslope should be treated as independent features with offsets adjusted for intervening slopes and the cost of the features summed.

The estimated severity indices in this table assume rounding is insufficient to have a beneficial effect. Where rounding in accordance with Section 4 of the Guide to Road Design – Part 3: Geometric Design *(Austroads 2009b) is provided, the severity index of the ditch should be taken as that for a slope through the beginning and end of the hinge rounding and the offset to the feature measured to the beginning of rounding.*

Where rounding is in between recommended and ineffective (say 1/4 of recommended) severity index estimates should be reduced to reflect more favourable conditions.



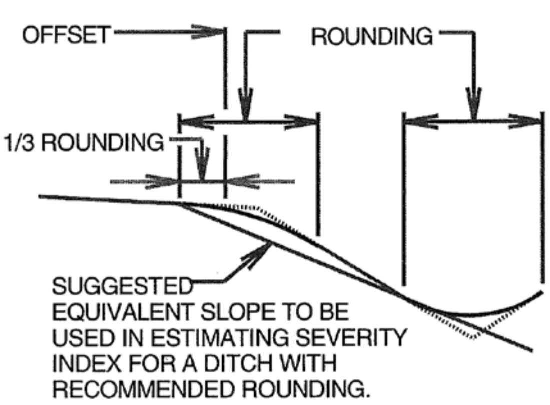


Table E 5: Suggested severity indices – intersecting slopes – negative (down)

Object type and characteristics				Object surface (*)	Severity index, SI							
Slope (H:V)	Height (m)	Surface condition (**)			Design speed (km/h)							
					50	60	70	80	90	100	110	120
Intersecting slopes (neg.) 10:1	0.3	A	See notes at end of Table	S	0.7	0.8	1.0	1.1	1.4	1.7	2.0	2.3
		B		S	0.9	1.0	1.2	1.3	1.4	1.6	2.2	2.9
		C		S	1.2	1.4	1.6	1.8	1.9	2.1	2.8	3.5
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	> 1.0	A	See notes at end of Table	S	0.6	0.8	1.0	1.2	1.5	1.9	2.3	2.7
		B		S	0.8	1.0	1.2	1.4	1.7	2.1	2.6	3.1
		C		S	1.1	1.4	1.6	1.9	2.2	2.6	3.2	3.7
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
Intersecting slopes (neg.) 8:1	0.3	A	See notes at end of Table	S	1.3	1.4	1.6	1.7	1.9	2.1	2.4	2.7
		B		S	1.5	1.6	1.8	1.9	2.1	2.3	2.7	3.1
		C		S	1.8	2.0	2.2	2.4	2.6	2.9	3.3	3.7
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	1	A	See notes at end of Table	S	1.4	1.6	1.8	2.0	2.2	2.5	3.0	3.5
		B		S	1.6	1.8	2.0	2.2	2.4	2.7	3.3	3.8
		C		S	1.9	2.2	2.4	2.7	2.9	3.2	3.8	4.5
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	2	A	See notes at end of Table	S	1.4	1.6	1.8	2.0	2.3	2.7	3.2	3.7
		B		S	1.6	1.8	2.0	2.2	2.5	2.9	3.5	4.0
		C		S	1.9	2.2	2.4	2.7	3.0	3.4	4.0	4.7
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	≥ 4	A	See notes at end of Table	S	1.4	1.6	1.8	2.0	2.3	2.7	3.3	3.8
		B		S	1.6	1.8	2.0	2.2	2.5	2.9	3.5	4.2
		C		S	1.9	2.2	2.4	2.7	3.0	3.4	4.1	4.8

Object type and characteristics				Object surface (*)	Severity index, SI							
Slope (H:V)	Height (m)	Surface condition (**)			Design speed (km/h)							
					50	60	70	80	90	100	110	120
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
Intersecting slopes (neg.) 6:1	0.3	A	See notes at end of Table	S	1.7	1.8	2.0	2.1	2.3	2.5	2.7	3.0
		B		S	1.9	2.0	2.2	2.3	2.5	2.7	3.0	3.3
		C		S	2.2	2.4	2.6	2.8	3.0	3.2	3.6	4.0
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	1	A	See notes at end of Table	S	2.1	2.3	2.5	2.7	2.9	3.3	3.7	4.1
		B		S	2.3	2.5	2.7	2.9	3.1	3.5	4.0	4.5
		C		S	2.6	2.9	3.1	3.4	3.6	4.0	4.6	5.1
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	2	A	See notes at end of Table	S	2.3	2.6	2.9	3.2	3.5	3.9	4.4	4.9
		B		S	2.5	2.8	3.1	3.4	3.7	4.1	4.7	5.2
		C		S	2.8	3.1	3.5	3.9	4.2	4.6	5.2	5.7
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	4	A	See notes at end of Table	S	2.2	2.5	2.9	3.3	3.7	4.2	4.8	5.3
		B		S	2.4	2.7	3.1	3.5	3.9	4.4	5.0	5.5
		C		S	2.7	3.1	3.5	4.0	4.4	4.9	5.5	6.0
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	6	A	See notes at end of Table	S	2.2	2.5	2.9	3.3	3.7	4.2	4.9	5.5
		B		S	2.4	2.7	3.1	3.5	3.9	4.4	5.0	5.6
		C		S	2.7	3.1	3.5	4,0	4.4	4.9	5.5	6.0
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	≥ 8	A	See notes at end of Table	S	2.2	2.5	2.9	3.3	3.7	4.2	4.9	5.6
		B		S	2.4	2.7	3.1	3.5	3.9	4.4	5.0	5.7
		C		S	2.7	3.1	3.5	4.0	4.4	4.9	5.5	6.0
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
Intersecting slopes (neg.) 4:1	0.3	A	See notes at end of Table	S	1.9	2.0	2.2	2.3	2.5	2.7	2.9	3.2
		B		S	2.1	2.2	2.4	2.5	2.7	2.9	3.2	3.5
		C		S	2.4	2.6	2.8	3.0	3.2	3.4	3.8	4.2
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3 .	7.0
	1	A	See notes at end of Table	S	2.6	2.8	3.0	3.2	3.4	3.6	4.0	4.4
		B		S	2.8	3.0	3.2	3.4	3.6	3.9	4.3	4.7
		C		S	3.1	3.4	3.6	3.9	4.1	4.4	4.9	5.4

Object type and characteristics				Object surface (*)	Severity index, SI							
Slope (H:V)	Height (m)	Surface condition (**)			Design speed (km/h)							
					50	60	70	80	90	100	110	120
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	2	A	See notes at end of Table	S	3.5	3.7	3.9	4.1	4.3	4.6	5.0	5.4
		B		S	3.6	3.8	4.0	4.2	4.5	4.8	5.2	5.6
		C		S	3.8	4.1	4.3	4.6	5.0	5.3	5.7	6.1
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	4	A	See notes at end of Table	S	3.7	4.1	4.5	5.0	5.2	5.5	5.9	6.3
		B		S	3.8	4.2	4.6	5.1	5.4	5.7	6.1	6.5
		C		S	4.0	4.5	5.0	5.5	5.8	6.2	6.6	7.0
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	6	A	See notes at end of Table	S	3.7	4.2	4.7	5.2	5.6	6.0	6.4	6.8
		B		S	3.8	4.3	4.8	5.3	5.8	6.2	6.6	7.0
		C		S	3.9	4.5	5.1	5.7	6.1	6.6	7.0	7.4
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	8	A	See notes at end of Table	S	3.7	4.3	4.8	5.4	5.9	6.4	6.8	7.2
		B		S	3.8	4.4	4.9	5.5	6.1	6.6	7.0	7.4
		C		S	3.9	4.5	5.2	5.8	6.4	7,0	7.4	7.8
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	10	A	See notes at end of Table	S	3.7	4.3	4.8	5.4	6.0	6.6	7.2	7.7
		B		S	3.8	4.4	4.9	5.5	6.2	6.8	7.3	7.8
		C		S	3.9	4.5	5.2	5.8	6.5	7.1	7.5	7.9
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5 9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	≥ 14	A	See notes at end of Table	S	3.7	4.3	4.8	5.4	6.0	6.6	7.2	7.9
		B		S	3.8	4.4	4.9	5.5	6.2	6.8	7.4	7.9
		C		S	3.9	4.5	5.2	5.8	6.5	7.1	7.5	7.9
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
Intersecting slopes (neg.) 3:1	0.3	A	See notes at end of Table	S	1.9	2.0	2.2	2.3	2.5	2.7	2.9	3.2
		B		S	2.1	2.2	2.4	2.5	2.7	2.9	3.2	3.5
		C		S	2.4	2.6	2.8	3.0	3.2	3.4	3.8	4.2
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	1	A	See notes at end of Table	S	2.7	2.9	3.1	3.3	3.5	3.7	4.0	4.3
		B		S	2.7	3.0	3.2	3.5	3.6	*3.9*	4.3	4.7
		C		S	3.1	3.4	3.6	3.9	4.1	4.4	4.9	5.4

Object type and characteristics				Object surface (*)	Severity index, SI							
Slope (H:V)	Height (m)	Surface condition (**)			Design speed (km/h)							
					50	60	70	80	90	100	110	120
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	2	A	See notes at end of Table	S	3.8	4.0	4.2	4.4	4.6	4.8	5.1	5.4
		B		S	3.9	4.1	4.3	4.5	4.7	5.0	5.3	5.6
		C		S	4.2	4.4	4.6	4.8	5.0	5.3	5.6	5.9
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	4	A	See notes at end of Table	S	4.8	5.0	5.2	5.4	5.7	6.0	6.2	6.5
		B		S	4.9	5.1	5.3	5.5	5.9	6.2	6.4	6.7
		C		S	5.1	5.3	5.5	5.7	6.1	6.4	6.8	7.2
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	6	A	See notes at end of Table	S	4.9	5.3	5.7	6.1	6.4	6.7	6.9	7.2
		B		S	5.0	5.4	5.8	6.2	6.6	6.9	7.1	7.4
		C		S	5.2	5.6	5.9	6.3	6.7	7.0	7.3	7.7
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	8	A	See notes at end of Table	S	5.0	5.6	6.1	6.7	7.0	7.3	7.5	7.8
		B		S	5.1	5.7	6.2	6.8	7.2	7.5	7.7	8.0
		C		S	5.2	5.8	6.3	6.9	7.3	7.6	7.8	8.1
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	10	A	See notes at end of Table	S	4.9	5.6	6.3	7.0	7.4	7.8	8.2	8.6
		B		S	5.0	5.7	6.4	7.1	7.5	7.9	8.3	8.7
		C		S	5.1	5.8	6.5	7.2	7.6	8.0	8.4	8.8
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	14	A	See notes at end of Table	S	4.9	5.6	6.3	7.0	7.5	7.9	8.3	8.7
		B		S	5.0	5.7	6.4	7.1	7.5	7.9	8.3	8.7
		C		S	5.1	5.8	6.5	7.2	7.6	8.0	8.4	8.8
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	≥ 18	A	See notes at end of Table	S	4.9	5.6	6.3	7.0	7.5	8.0	8.4	8.8
		B		S	5.0	5.7	6.4	7.1	7.6	8.0	8.4	8.8
		C		S	5.1	5.8	6.5	7.2	7.6	8.0	8.4	8.8
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
Intersecting slopes (neg.) 2:1	0.3	A	See notes at end of Table	S	1.9	2.0	2.2	2.3	2.5	2.7	2.9	3.2
		B		S	2.1	2.2	2.4	2.5	2.7	2.9	3.2	3.5
		C		S	2.4	2.6	2.8	3.0	3.2	3.4	3.8	4.2

Object type and characteristics				Object surface (*)	Severity index, SI							
Slope (H:V)	Height (m)	Surface condition (**)			Design speed (km/h)							
					50	60	70	80	90	100	110	120
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	1	A	See notes at end of Table	S	2.9	3.0	3.2	3.3	3.5	3.7	4.0	4.3
		B		S	2.9	3.1	3.3	3.5	3.6	3.9	4.3	4.7
		C		S	3.3	3.5	3.7	3.9	4.1	4.4	4.9	5.4
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	2	A	See notes at end of Table	S	4.1	4.2	4.4	4.5	4.7	4.9	5.1	5.4
		B		S	4.1	4.2	4.4	4.5	4.7	5.0	5.3	5.6
		C		S	4.2	4.4	4.6	4.8	5.0	5.3	5.6	5.9
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	4	A	See notes at end of Table	S	5.5	5.6	5.6	5.7	5.9	6.2	6.4	6.5
		B		S	5.5	5.6	5.6	5.7	6.0	6.3	6.5	6.6
		C		S	5.6	5.7	5.7	5.8	6.1	6.4	6.6	6.7
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	6	A	See notes at end of Table	S	6.0	6.2	6.4	6.6	6.8	7.1	7.3	7.4
		B		S	6.0	6.2	6.4	6.6	6.9	7.2	7.4	7.5
		C		S	6.1	6.3	6.5	6.7	7.0	7.3	7.5	7.6
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	8	A	See notes at end of Table	S	6.5	6.8	7.1	7.4	7.6	7.9	8.1	8.2
		B		S	6.5	6.8	7.1	7.4	7.7	8.0	8.2	8.3
		C		S	6.6	6.9	7.2	7.5	7.8	8.1	8.3	8.4
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	10	A	See notes at end of Table	S	7.0	7.4	7.8	8.3	8.5	8.7	8.9	9.0
		B		S	7.0	7.4	7.8	8.3	8.5	8.8	9.0	9.1
		C		S	7.1	7.5	7.9	8.4	8.6	8.9	9.1	9.2
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	14	A	See notes at end of Table	S	7.2	7.6	8.0	8.5	8.7	9.0	9.2	9.3
		B		S	7.2	7.6	8.0	8.5	8.7	9.0	9.2	9.3
		C		S	7.2	7.6	8.0	8.5	8.7	9.0	9.2	9.3
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	18	A		S	7.3	7.7	8.1	8.6	8.9	9.1	9.3	9.4
		B		S	7.3	7.7	8.1	8.6	8.9	9.1	9.3	9.4

Object type and characteristics				Object surface (*)	Severity index, SI							
Slope (H:V)	Height (m)	Surface condition (**)			Design speed (km/h)							
					50	60	70	80	90	100	110	120
		C	See notes at end of Table	S	7.3	7.7	8.1	8.6	8.9	9.1	9.3	9.4
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	22	A	See notes at end of Table	S	7.2	7.7	8.2	8.7	8.9	9.1	9.3	9.4
		B		S	7.2	7.7	8.2	8.7	8.9	9.1	9.3	9.4
		C		S	7.2	7.7	8.2	8.7	8.9	9.1	9.3	9.4
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
Intersecting slopes (neg.) 1½:1	0.3	A	See notes at end of Table	S	1.9	2.0	2.2	23	2.5	2.7	2.9	3.2
		B		S	2.1	2.2	2.4	2.5	2.7	2.9	3.2	3.5
		C		S	2.4	2.6	2.8	3.0	3.2	3.4	3.8	4.2
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	1	A	See notes at end of Table	S	2.9	3.0	3.2	3.3	3.5	3.7	4.0	4.3
		B		S	2.9	3.1	3.3	3.5	3.6	3.9	4.3	4.7
		C		S	3.3	3.5	3.7	3.9	4.1	4.4	4.9	5.4
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	2	A	See notes at end of Table	S	4.1	4.2	4.4	4.5	4.7	4.9	5.1	5.4
		B		S	4.1	4.2	4.4	4.5	4.7	5.0	5.3	5.6
		C		S	4.2	4.4	4.6	4.8	5.0	5.3	5.6	5.9
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	4	A	See notes at end of Table	S	5.6	5.7	5.7	5.8	6.0	6.2	6.4	6.5
		B		S	5.6	5.7	5.7	5.8	6.0	6.3	6.5	6.6
		C		S	5.5	5.6	5.8	5.9	6.1	6.4	6.6	6.7
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	6	A	See notes at end of Table	S	6.3	6.5	6.6	6.7	6.9	7.1	7.4	7.4
		B		S	6.3	6.5	6.6	6.7	6.9	7.2	7.4	7.5
		C		S	6.3	6.5	6.6	6.7	6.9	7.2	7.4	7.5
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	8	A	See notes at end of Table	S	7.0	7.2	7.4	7.6	7.8	8.0	8.2	8.3
		B		S	7.0	7.2	7.4	7.6	7.8	8.0	8.2	8.3
		C		S	7.0	7.2	7.4	7.6	7.8	8.0	8.2	8.3
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	10	A		S	7.9	8.2	8.5	8.8	8.9	8.9	9.1	9.2
		B		S	7.9	8.2	8.5	8.8	8.9	8.9	9.1	9.2

Object type and characteristics				Object surface (*)	Severity index, SI							
Slope (H:V)	Height (m)	Surface condition (**)			Design speed (km/h)							
					50	60	70	80	90	100	110	120
		C	See notes at end of Table	S	7.9	8.2	8.5	8.8	8.9	8.9	9.1	9.2
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	14	A	See notes at end of Table	S	8.3	8.6	8.8	9.1	9.2	9.3	9.5	9.6
		B		S	8.3	8.6	8.8	9.1	9.2	9.3	9.5	9.6
		C		S	8.3	8.6	8.8	9.1	9.2	9.3	9.5	9.6
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	18	A	See notes at end of Table	S	8.5	8.8	9.0	9.3	9.4	9.5	9.5	9.5
		B		S	8.5	8.8	9.0	9.3	9.4	9.5	9.6	9.6
		C		S	8.5	8.8	9.0	9.3	9.4	9.5	9.6	9.6
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	≥ 22	A	See notes at end of Table	S	8.6	8.9	9.1	9.4	9.5	9.5	9.6	9.6
		B		S	8.6	8.9	9.1	9.4	9.5	9.5	9.6	9.6
		C		S	8.6	8.9	9.1	9.4	9.5	9.5	9.6	9.6
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0

**S = Approach Side, C = Corner, F = Traffic Face, A = S, C, and F.*

***Surface conditions are assumed to continue on surface beyond slope.*

Notes:

A. Smooth and firm all seasons.

B. Smooth but subject to deep rutting by errant vehicles half of the year.

C. Shallow gullies (I00 to 200 mm deep), scattered small boulders (under 225 mm projections), scattered small trees (diameters 75 to 100 mm), or structurally substantial woody brush. Features spaced so that nearly all encroaching vehicles will encounter them.

D. Medium gullies (approximately 250 mm deep), boulders or riprap (projecting approximately 300 mm), or medium trees (diameters 175 to 225 mm). Features spaced so that they will be encountered by all encroaching vehicles. It is assumed that density of features will preclude deep penetration of roadside. If this assumption is not valid, severity indices for high, steep slopes may be considerably higher than values shown.

E. Deep gullies (over 0.5 m deep), large boulders or heavy riprap (over 450 mm projecting), large trees (diameters over 350 mm). Features spaced so that they will be encountered by all encroaching vehicles. It is assumed that density of features will preclude deep penetration of roadside. If this assumption is not valid, severity indices for high, steep slopes may be considerably higher than values shown.

Table E 6: Suggested severity indices – intersecting slopes – vertical drop with and without water present

Object type and characteristics			Object surface (*)	Severity index							
				Design speed (km/h)							
Slope (H:V)	Height (m)	Water depth (**)		50	60	70	80	90	100	110	120
Intersecting slopes vertical drop	0	0	S	0.1	0.2	0.2	0.3	0.4	0.5	0.7	0.8
		1	S	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.7
		2	S	4.3	4.6	4.8	5.1	5.3	5.6	5.8	6.1
		4	S	6.0	6.2	6.4	6.6	6.8	7.0	7.2	7.5
		≥ 6	S	7.5	7.7	7.9	8.1	8.3	8.4	8.6	8.7
	0.3	0	S	1.9	2.0	2.2	2.3	2.5	2.7	2.9	3.2
		1	S	2.6	2.9	3.1	3.4	3.6	3.9	4.1	4.4
		2	S	4.3	4.6	4.9	5.2	5.6	5.9	6.3	6.7
		4	S	6.0	6.3	6.6	6.9	7.1	7.4	7.6	7.9
		≥ 6	S	7.9	8.0	8.2	8.3	8.5	8.7	8.9	9.0
	1.0	0	S	2.9	3.0	3.2	3.3	3.5	3.7	4.0	4.3
		1	S	3.2	3.4	3.6	3.8	4.0	4.2	4.5	4.8
		2	S	5.4	5.6	5.8	6.0	6.3	6.6	6.8	7.1
		4	S	6.5	6.8	7.0	7.3	7.5	7.7	7.9	8.2
		≥ 6	S	8.0	8.1	8.3	8.4	8.6	8.8	9.0	9.1
	2.0	0	S	4.1	4.2	4.4	4.5	4.7	4.9	5.1	5.4
		1	S	4.2	4.4	4.6	4.8	5.0	5.2	5.4	5.7
		2	S	6.5	6.6	6.8	6.9	7.1	7.3	7.5	7.6
		4	S	7.3	7.4	7.6	7.7	7.9	8.1	8.3	8.4
		≥ 6	S	8.1	8.2	8.4	8.5	8.7	8.9	9.1	9.2
	4.0	0	S	5.7	5.8	5.8	5.9	6.0	6.2	6.4	6.5
		1	S	5.7	5.8	6.0	6.1	6.2	6.4	6.7	7.0
		2	S	7.2	7.3	7.5	7.6	7.8	8.0	8.2	8.3
		4	S	7.8	7.9	8.1	8.2	8.4	8.6	8.8	8.9
		≥ 6	S	8.4	8.5	8.7	8.8	9.0	9.2	9.4	9.5
	≥ 8.0	Any depth	S	Use values from foreslopes – vertical							

**S = Approach Side, C = Corner, F = Traffic Face, A = S, C, and F.*

***Surface conditions are assumed to continue on surface beyond slope.*

Table E 7: Suggested severity indices – intersecting slopes – positive (up)**

Object type and characteristics				Object surface (*)	Severity index, SI							
Slope (H:V)	Height (m)	Surface condition			Design speed (km/h)							
					50	60	70	80	90	100	110	120
Intersecting slopes (pos) 10:1	0.15	A	See notes at end of Table	S	0.3	0.4	0.6	0.7	0.9	1.1	1.3	1.6
		B		S	0.5	0.6	0.8	0.9	1.1	1.3	1.5	1.8
		C		S	0.9	1.0	1.2	1.3	1.5	1.7	2.0	2.3
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.3	A	See notes at end of Table	S	0.4	0.5	0.7	0.8	1.2	1.5	1.9	2.3
		B		S	0.6	0.7	0.9	1.0	1.4	1.7	2.1	2.5
		C		S	0.8	1.0	1.2	1.4	1.8	2.1	2.5	2.9
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.6	A	See notes at end of Table	S	0.4	0.5	0.7	0.8	1.2	1.6	2.0	2.4
		B		S	0.6	0.7	0.9	1.0	1.4	1.8	2.2	2.6
		C		S	0.8	1.0	1.2	1.4	1.8	2.2	2.6	3.0
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
Intersecting slopes (pos) 8:1	0.15	A	See notes at end of Table	S	0.3	0.4	0.6	0.7	0.9	1.1	1.3	1.6
		B		S	0.5	0.6	0.8	0.9	1.1	1.3	1.5	1.8
		C		S	0.9	1.0	1.2	1.3	1.5	1.7	2.0	2.3
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.3	A	See notes at end of Table	S	0.4	0.6	0.8	1.0	1.5	2.0	2.2	2.5
		B		S	0.6	0.8	1.0	1.2	1.7	2.1	2.4	2.7
		C		S	0.8	1.1	1.3	1.6	2.1	2.5	2.8	3.1
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.6	A	See notes at end of Table	S	0.3	0.6	0.9	1.2	1.7	2.1	2.3	2.4
		B		S	0.5	0.8	1.0	1.3	1.8	2.2	2.4	2.7
		C		S	0.8	1.1	1.4	1.7	2.2	2.6	2.8	3.1
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	1	A	See notes at end of Table	S	0.3	0.6	0.9	1.2	1.7	2.1	2.3	2.6
		B		S	0.5	0.8	1.1	1.4	1.8	2.2	2.5	2.8
		C		S	0.7	1.0	1.4	1.8	2.2	2.6	2.9	3.2
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0

Object type and characteristics				Object surface (*)	Severity index, SI							
Slope (H:V)	Height (m)	Surface condition			Design speed (km/h)							
					50	60	70	80	90	100	110	120
Intersecting slopes (pos) 6:1	0.15	A	See notes at end of Table	S	0.3	0.4	0.6	0.7	0.9	1.1	1.3	1.6
		B		S	0.5	0.6	0.8	0.9	1.1	1.3	1.5	1.8
		C		S	0.7	0.9	1.1	1.3	1.5	1.8	2.0	2.3
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.3	A	See notes at end of Table	S	0.5	0.8	1.2	1.6	2.0	2.3	2.6	2.9
		B		S	0.7	1.0	1.4	1.8	2.1	2.4	2.8	3.2
		C		S	1.0	1.3	1.7	2.1	2.4	2.7	3.1	3.5
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.6	A	See notes at end of Table	S	0.5	0.9	1.3	1.8	2.1	2.4	2.7	3.0
		B		S	0.8	1.1	1.5	1.9	2.2	2.5	2.9	3.3
		C		S	1.0	1.4	1.8	2.3	2.5	2.8	3.2	3.6
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	1	A	See notes at end of Table	S	0.4	0.9	1.4	1.9	2.2	2.5	2.8	3.1
		B		S	0.7	1.1	1.5	2.0	2.3	2.6	3.0	3.4
		C		S	0.9	1.4	1.9	2.4	2.6	2.9	3.3	3.7
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
Intersecting slopes (pos) 4:1	0.15	A	See notes at end of Table	S	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.7
		B		S	0. 4	0.6	0.8	1.0	1.2	1.4	1.6	1.9
		C		S	0.6	0.9	1.1	1.4	1.6	1.8	2.1	2.4
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.3	A	See notes at end of Table	S	1.3	1.6	1.9	2.2	2.6	3.0	3.3	3.6
		B		S	1.5	1.8	2.0	2.3	2.7	3.1	3.5	3.9
		C		S	1.8	2.1	2.3	2.6	3.0	3.4	3.8	4.2
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.6	A	See notes at end of Table	S	1.6	1.9	2.1	2.4	2.8	3.2	3.5	3.8
		B		S	1.7	2.0	2.2	2.5	2.9	3.3	3.6	3.9
		C		S	2.2	2.4	2.6	2.8	3.2	3.6	3.9	4.2
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	1	A	See notes at end of Table	S	1.6	1.9	2.1	2.4	2.8	3.2	3.6	4.0
		B		S	1.7	2.0	2.2	2.5	2.9	3.3	3.7	4.1
		C		S	2.2	2.4	2.6	2.8	3.2	3.6	4.0	4.4
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0

Object type and characteristics				Object surface (*)	Severity index, SI							
Slope (H:V)	Height (m)	Surface condition			Design speed (km/h)							
					50	60	70	80	90	100	110	120
Intersecting slopes (pos) 3:1	0.15	A	See notes at end of Table	S	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.7
		B		S	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.9
		C		S	0.6	0.9	1.1	1.4	1.6	1.8	2.1	2.4
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.3	A	See notes at end of Table	S	1.8	2.1	2.4	2.7	3.1	3.5	3.9	4.3
		B		S	1.9	2.2	2.5	2.8	3.2	3.6	4.0	4.4
		C		S	2.2	2.5	2.8	3.1	3.5	3.9	4.2	4.5
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.6	A	See notes at end of Table	S	1.8	2.1	2.5	2.9	3.3	3.7	4.1	4.5
		B		S	1.9	2.2	2.6	3.0	3.4	3.8	4.2	4.6
		C		S	2.2	2.5	2.9	3.3	3.7	4.0	4.4	4.8
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	1	A	See notes at end of Table	S	1.9	2.2	2.6	3.0	3.4	3.8	4.2	4.6
		B		S	2.0	2.3	2.7	3.1	3.5	3.9	4.3	4.7
		C		S	2.1	2.5	2.9	3.4	3.8	4.1	4.5	4.9
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
Intersecting slopes (pos) 2:1	0.15	A	See notes at end of Table	S	0.4	0.5	0.7	0.8	1.0	1.2	1.4	1.7
		B		S	0.6	0.7	0.9	1.0	1.2	1.4	1.6	1.9
		C		S	0.8	1.0	1.2	1.4	1.6	1.8	2.1	2.4
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.3	A	See notes at end of Table	S	2.1	2.5	2.9	3.4	3.9	4.4	4.8	5.2
		B		S	2.2	2.6	3.0	3.5	4.0	4.5	4.9	5.3
		C		S	2.3	2.8	3.3	3.8	4.2	4.7	5.1	5.5
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.6	A	See notes at end of Table	S	2.5	2.8	3.2	3.6	4.1	4.6	5.0	5.4
		B		S	2.6	2.9	3.3	3.7	4.2	4.7	5.1	5.5
		C		S	2.8	3.1	3.5	3.9	4.4	4.9	5.3	5.7
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	1	A	See notes at end of Table	S	2.6	2.9	3.3	3.7	4.2	4.7	5.1	5.5
		B		S	2.7	3.0	3.4	3.8	4.3	4.8	5.2	5.6
		C		S	2.9	3.2	3.6	4.0	4.5	4.9	5.3	5.7
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0

Object type and characteristics				Object surface (*)	Severity index, SI							
Slope (H:V)	Height (m)	Surface condition			Design speed (km/h)							
					50	60	70	80	90	100	110	120
Intersecting slopes (pos) 1½:1	0.15	A	See notes at end of Table	S	0.4	0.5	0.7	0.8	1.0	1.3	1.5	1.8
		B		S	0.6	0.7	0.9	1.0	1.2	1.5	1.7	2.0
		C		S	0.8	1.0	1.2	1.4	1.6	1.9	2.1	2.4
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.3	A	See notes at end of Table	S	2.4	2.9	3.4	3.9	4.3	4.8	5.3	5.8
		B		S	2.5	3.0	3.5	4.0	4.4	4.9	5.4	5.9
		C		S	2.7	3.2	3.7	4.2	4.6	5.1	5.5	5.9
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.6	A	See notes at end of Table	S	2.6	3.1	3.6	4.1	4.6	5.2	5.6	6.0
		B		S	2.7	3.2	3.7	4.2	4.7	5.3	5.7	6.1
		C		S	2.9	3.4	3.9	4.4	4.9	5.4	5.8	6.2
		D		S	2.9	3.4	3.9	4.4	4.9	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	1	A	See notes at end of Table	S	2.7	3.2	3.7	4.2	4.7	5.3	5.7	6.1
		B		S	2.8	3.3	3.8	4.3	4.8	5.4	5.8	6.2
		C		S	3.0	3.5	4.0	4.5	5.0	5.5	5.9	6.3
		D		S	3.0	3.5	4.0	4.5	5.0	5.5	5.9	6.3
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
Intersecting Slopes (pos) 1:1	0.15	A	See notes at end of Table	S	0.4	0.5	0.7	0.8	1.0	1.3	1.5	1.8
		B		S	0.6	0.7	0.9	1.0	1.2	1.5	1.7	2.0
		C		S	0.8	1.0	1.2	1.4	1.6	1.9	2.1	2.4
		D		S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.3	A	See notes at end of Table	S	2.9	3.3	3.7	4.2	4.7	5.3	5.8	6.3
		B		S	3.0	3.4	3.8	4.3	4.8	5.4	5.8	6.2
		C		S	3.2	3.6	4.0	4.5	5.0	5.5	5.9	6.3
		D		S	3.2	3.6	4.0	4.5	5.0	5.5	5.9	6.4
		E		S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	7.0
	0.6	A	See notes at end of Table	S	3.0	3.5	4.0	4.5	5.0	5.6	6.2	6.7
		B		S	3.1	3.6	4.1	4.6	5.1	5.6	6.2	6.7
		C		S	3.3	3.8	4.3	4.8	5.2	5.7	6.3	6.8
		D		S	3.3	3.8	4.3	4.8	5.2	5.7	6.3	6.8
		E		S	3.3	3.8	4.3	4.8	5.2	5.7	6.3	7.0
	1	A	See notes at end of Table	S	3.1	3.6	4.1	4.6	5.1	5.7	6.3	6.8
		B		S	3.2	3.7	4.2	4.7	5.2	5.7	6.3	6.8
		C		S	3.4	3.9	4.4	4.9	5.3	5.8	6.4	6.9
		D		S	3.4	3.9	4.4	4.9	5.3	5.8	6.4	6.9
		E		S	3.4	3.9	4.4	4.9	5.3	5.8	6.4	6.9

**S = Approach Side, C = Corner, F = Traffic Face, A = S, C, and F.*

***The condition addressed in this table is a relatively simple one where the vehicle encounters an intersecting upward slope that connects to a relatively level and wide surface at its upper limit. Transitions between foreslopes or backslopes and intersecting slopes are not addressed, nor is the condition where a vehicle might vault over a dike or a narrow intersecting roadway. Developing SIs for the conditions not addressed will require special analysis and engineering judgement.*

Notes:

A. Smooth and firm all seasons.

B. Smooth but subject to deep rutting by errant vehicles half of the year.

C. Shallow gullies (I00 to 200 mm deep), scattered small boulders (under 225 mm projections), scattered small trees (diameters 75 to 100 mm), or structurally substantial woody brush. Features spaced so that nearly all encroaching vehicles will encounter them.

D. Medium gullies (approximately 250 mm deep), boulders or riprap (projecting approximately 300 mm), or medium trees (diameters 175 to 225 mm). Features spaced so that they will be encountered by all encroaching vehicles. It is assumed that density of features will preclude deep penetration of roadside. If this assumption is not valid, severity indices for high, steep slopes may be considerably higher than values shown.

E. Deep gullies (over 0.5 m deep), large boulders or heavy riprap (over 450 mm projecting), large trees (diameters over 350 mm). Features spaced so that they will be encountered by all encroaching vehicles. It is assumed that density of features will preclude deep penetration of roadside. If this assumption is not valid, severity indices for high, steep slopes may be considerably higher than values shown.

Table E 8: Suggested severity indices – traffic barriers

Object type and characteristics	Object surface (*)	Severity index							
		Design speed (km/h)							
		50	60	70	80	90	100	110	120
Longitudinal traffic barriers									
Uniform section									
Basic SI For all currently accepted barriers, guardrails, bridge rails, median barriers, apply the basic SI to that percentage of impacts estimated to be contained by the barrier. For that percentage of impacts estimated to penetrate an SI appropriate for the shielded hazard should be used to adjust the effective barrier SI	F	1.9	2.0	2.2	2.3	2.5	2.7	3.0	3.3
Basic SI Non-blocked out W-beam on strong posts with 1.9 m post spacing (adjust for estimated penetrations)	F	2.0	2.1	2.3	2.4	2.7	3.0	3.3	3.6
Basic SI Cable on strong posts (adjust for estimated penetrations)	F	2.0	2.2	2.4	2.6	2.8	3.1	3.4	3.7
For walls and parapets with irregular surfaces estimate SIs by referring to vertical backslopes	F	-	-	-	-	-	-	-	-
Safety barrier to parapet transitions									
Treat the same as currently acceptable longitudinal barriers if transition meets crash test acceptance requirements and adjust for estimated penetrations	F	1.9	2.0	2.2	2.3	2.5	2.7	3.0	3.3

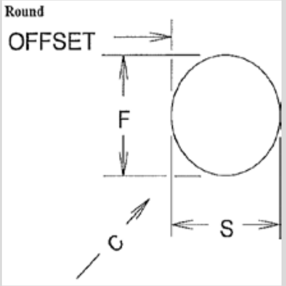
Object type and characteristics	Object surface (*)	Severity index							
		Design speed (km/h)							
		50	60	70	80	90	100	110	120
For substandard transitions consider a section of the face of the approach guardrail as having the severity of a fixed object. This section of barrier would nominally be part of a continuous barrier face, thus the corner and side SIs would be zero.									
Examples: Standard, strong-post, W-beam guardrail, blocked out with two spaces at 0.95 m and full-strength attachment to parapet	F	0.1 m @ 1.8**	0.1 m @ 2.0	0.3 m @ 2.2	0.4 m @ 2.4	0.7 m @ 2.6	1.1 m @ 2.9	1.6 m @ 3.2	2.0 m @ 3.5
Standard, strong-post, W-beam guardrail, blocked out, with 1.9 m post spacing and no connection to parapet	F	0.4 m @ 2.0	0.7 m @ 2.3	1.1 m @ 2.5	1.5 m @ 2.8	2.1 m @ 3.2	2.7 m @ 3.5	3.5 m @ 3.9	4.2 m @ 4.3
Three cable guardrail, 4.88 m post spacing, attached to parapet end	F	2.4 m @ 3.0	2.8 m @ 3.4	3.3 m @ 3.8	3.8 m @ 4.3	4.5 m @ 4.8	5.5 m @ 5.4	6.9 m @ 6.0	8.4 m @ 6.5
Terminals (approach end except where noted)									
Stand-up W-beam, unanchored, with no safety treatment and no flare. The first metre or so of the unanchored rail will have diminished effectiveness and have a higher SI than the remainder of the guardrail. The values given here for that section of guardrail may require adjustment for penetration to the shielded object	C&S	4.1	4.3	4.5	4.7	5.0	5.3	5.6	5.9
	F	1.0 m @ 2.2	1.6 m @ 2.5	2.1 m @ 2.7	2.7 m @ 3.0	3.3 m @ 3.2	4.1 m @ 3.4	5.2 m @ 3.8	6.3 m @ 4.2
Break away cable terminal (BCT) without diaphragms (properly installed with recommended flare)	C&S	3.0	3.3	3.6	3.9	4.1	4.3	4.5	4.8
	F	1.8 m @ 2.1	1.8 m @ 2.3	1.8 m @ 2.5	1.8 m @ 2.7	1.8 m @ 2.9	1.8 m @ 3.2	1.8 m @ 3.5	1.8 m @ 3.8
Turned-down W-beam (7.5 m twist)	C&S	2.7	2.9	3.1	3.3	3.7	4.0	4.3	4.6
	F	5.5 m @ 2.8	5.5 m @ 3.0	5.5 m @ 3.2	5.5 m @ 3.4	5.5 m @ 3.8	5.5 m @ 4.1	5.5 m @ 4.4 ,	5.5 m @ 4.7
Three-cable, wood-post guardrail terminal with cables anchored to end post and end post restrained by a rod attached to a deadman. Approach end	C&S	3.0	3.3	3.5	3.8	4.2	4.6	5.0	5.4
Exit end (treat as fixed object)	C&S	2.7	3.1	3.5	4.0	4.5	5.0	5.5	6.0
Break away cable terminal with diaphragm (properly installed with recommended flare)	C&S	2.9	3.1	3.3	3.5	3.7	3.9	4.1	4.4
	F	2 m @ 2.1	2 m @ 2.3	2 m @ 2.5	2 m @ 2.7	2 m @ 2.9	2 m @ 3.2	2 m @ 3.5	2 m @ 3.8
CAT, ET2000, Brakemaster, MELT	C&S	2.0	2.2	2.4	2.6	2.9	3.2	3.5	3.8
	F	2 m @ 2.1	2 m @ 2.3	2 m @ 2.5	2 m @ 2.7	2 m @ 2.9	2 m @ 3.2	2 m @ 3.5	2 m @ 3.8

Object type and characteristics	Object surface (*)	Severity index							
		Design speed (km/h)							
		50	**60**	**70**	**80**	**90**	**100**	**110**	**120**
Buried in backslope – The SI components for this type of terminal will be dependent on the configuration of the backslope, the ditch cross section, the terminus flare rate, and the conditions reachable by vehicles penetrating the terminal area. Values given here assume a 3:1 backslope paralleling the roadway at the point of burial, top of guardrail parallels the roadway at point of burial, top of guardrail parallels the roadway grade, the ditch is modified to provide a berm for carrying the flaring guardrails, grading approaching the berm is sufficiently gentle to have minimal effect on approach vehicle trajectory, and the guardrail at flare rates for 50, 60, 70, 80, 90, 100, 110, and 120 km/h are 9:1, 10:1, 11:1, 12:1, 13:1, 14:1, 15:1, and 16:1 respectively	C&S	0.6	0.7	0.9	1.0	1.2	1.5	1.7	2.0
	F	4 m @ 2.0	4 m @ 2.2	4 m @ 2,4	4 m @ 2.6	4 m @ 2.8	4 m @ 3.1	4 m @ 3.3	4 m @ 3.6
Three-cable, steel-post guardrail terminal with 5.5 m turndown and non-snag release feature for exit end impacts	C&S	1.9	2.0	2.2	2.3	2.5	2.7	3.0	3.3
	F	3 m @ 2.0	3 m @ 2.1	3 m @ 2.3	3 m @ 2.4	3 m @ 2.6	3 m @ 2.8	3 m @ 3.1	3 m @ 3.4
Eccentric loader terminal	C&S	2.0	2.2	2.4	2.6	2.8	3.1	3.4	3.7
	F	2 m @ 2.1	2 m @ 2.3	2 m @ 2.5	2 m @ 2.7	2 m @ 2.9	2 m @ 3.2	2 m @ 3.5	2 m @ 3.8
SENTRE	C&S	2.1	2.2	2.4	2.5	2.7	3.0	3.3	3.6
	F	2 m @ 1.9	2 m @ 2.0	2 m @ 2.2	2 m @ 2.3	2 m @ 2.5	2 m @ 2.7	2 m @ 2.9	2 m @ 3.2
Crash cushions									
Redirecting – design meets recommended performance requirements	C&S	2.1	2.2	2.4	2.5	2.7	3.0	3.3	3.6
	F	1.9	2.0	2.2	2.3	2.5	2.8	3.1	3.4
Non-redirecting – design meets recommended performance requirements, sand barrels have recommended 0.75 m shadow offset at rear of array – treat a section of the face at the rear of the array as having higher SI than that assigned to the remainder of the crash cushion. Consider section as part of a continuous barrier face. Thus the corner and side SIs of the section equal zero	C&S	1.9	2.0	2.2	2.3	2.5	2.8	3.1	3.4
	F	0.2 m @ 3.3	0.3 m @ 3.6	0.5 m @ 3.9	1.0 m @ 4.2	1.5 m @ 4.6	2.3 m @ 5.1	2.7 m @ 5.6	3.3 m @ 6.1

**S = Approach Side, C = Corner, F = Traffic Face, A = S, C, and F.*

*** Dimension above '@'sign is length of device to be analysed using the noted severity index.*

Table E 9: Suggested severity indices – fixed objects

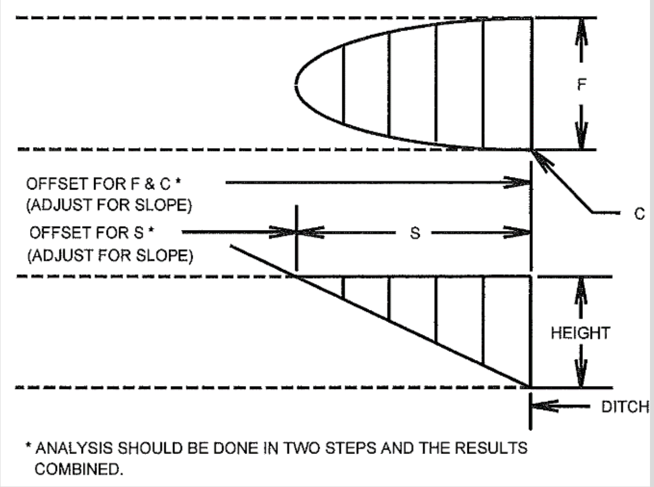
Object type and characteristics		Object surface (*)	Severity index							
			Design speed (km/h)							
			50	60	70	80	90	100	110	120
	Diameter equal to 0.5 m	S	3.0	3.4	3.8	4.3	4.8	5.4	6.0	6.5
		C	3.4	3.8	4.2	4.7	5.2	5.8	6.5	7.2
		F	2.6	3.0	3.4	3.9	4.4	4.9	5.3	5.7
	Diameter equal to 1 m	S	2.8	3.3	3.8	4.3	4.8	5.3	5.9	6.4
		C	3.3	3.7	4.1	4.6	5.1	5.7	6.4	7.1
		F	2.5	2.9	3.3	3.8	4.3	4.7	5.0	5.3
	Diameter equal to or greater than 2 m	S	2.7	3.2	3.7	4.2	4.7	5.3	5.9	6.4
		C	3.2	3.6	4.0	4.5	5.0	5.6	6.3	7.0
		F	2.6	2.9	3.3	3.7	4.2	4.7	5.2	5.7
Rectangular: Width of approach side equal to 0.5 m Face parallel to roadway, sides are perpendicular	Height = 0.15 m	S	0.2	0.3	0.5	0.6	0.7	0.8	0.9	0.9
		C	0.2	0.3	0.5	0.6	0.7	0.8	0.9	0.9
		F	0.4	0.5	0.7	0.8	1.0	1.2	1.4	1.5
	Height = 0.3 m	S	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		C	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		F	1.9	2.0	2.2	2.3	2.5	2.7	2.9	3.2
	Height = 0.5 m	S	3.2	3.6	4.0	4.5	5.1	5.7	6.3	6.8
		C	3.2	3.6	4.0	4.5	5.1	5.7	6.3	6.8
		F	1.9	2.0	2.2	2.3	2.5	2.7	2.9	3.2
	Height = 0.6 m	S	3.4	3.8	4.2	4.7	5.2	5.8	6.5	7.2
		C	3.4	3.8	4.2	4.7	5.2	5.8	6.5	7.2
		F	1.9	2.0	2.2	2.3	2.5	2.7	2.9	3.2
	Height > 1.0 m	S	3.4	3.9	4.4	4.9	5.4	6.0	6.7	7.4
		C	3.4	3.9	4.4	4.9	5.4	6.0	6.7	7.4
		F	1.9	2.0	2.2	2.3	2.5	2.7	2.9	3.2
Rectangular: Width of approach side is 1.25 m. Face is parallel to roadway, sides are perpendicular	Height = 0.15 m	S	0.5	0.6	0.8	0.9	1.1	1.3	1.5	1.8
		C	0.5	0.6	0.8	0.9	1.1	1.3	1.5	1.8
		F	0.4	0.5	0.7	0.8	1.0	1.2	1.4	1.5
	Height = 0.3 m	S	2.6	3.2	3.7	4.3	4.8	5.3	5.8	6.3
		C	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		F	1.9	2.0	2.2	2.3	2.5	2.7	2.9	3.2

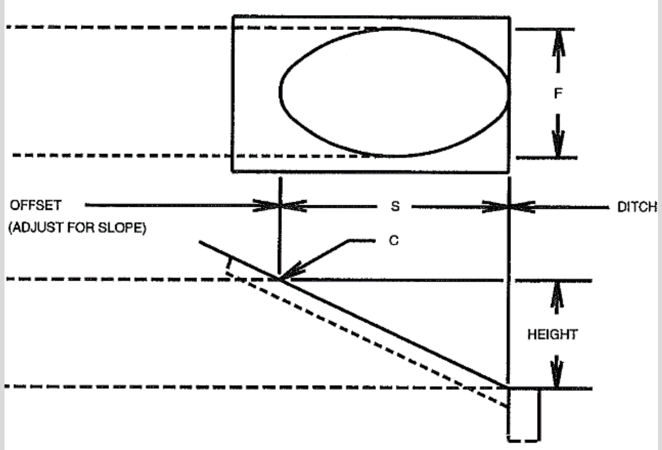
Object type and characteristics		Object surface (*)	Severity index							
			Design speed (km/h)							
			50	60	70	80	90	100	110	120
	Height = 0.5 m	S	3.0	3.5	4.0	4.5	5.0	5.6	6.2	6.7
		C	3.2	3.6	4.0	4.5	5.1	5.7	6.3	6.8
		F	1.9	2.0	2.2	2.3	2.5	2.7	2.9	3.2
	Height = 0.6 m	S	3.1	3.6	4.1	4.6	5.1	5.7	6.4	7.1
		C	3.4	3.8	4.2	4.7	5.2	5.8	6.5	7.2
		F	1.9	2.0	2.2	2.3	2.5	2.7	2.9	3.2
	Height > 1.0 m	S	3.3	3.8	4.3	4.8	5.3	5.9	6.6	7.3
		C	3.4	3.9	4.4	4.9	5.4	6.0	6.7	7.4
		F	1.9	2.0	2.2	2.3	2.5	2.7	2.9	3.2
Rectangular: Width of approach side is 2 m or greater. Face is parallel to traffic and sides are perpendicular.	Height = 0.15 m	S	0.5	0.7	0.9	1.1	1.3	1.6	1.9	2.2
		C	0.5	0.7	0.9	1.1	1.3	1.6	1.9	2.2
		F	0.4	0.5	0.7	0.8	1.0	1.2	1.4	1.5
	Height = 0.3 m	S	2.5	3.1	3.6	4.2	4.7	5.3	5.8	6.3
		C	2.8	3.3	3.8	4.3	4.8	5.4	5.9	6.4
		F	1.9	2.0	2.2	2.3	2.5	2.7	3.0	3.3
	Height = 0.5 m	S	2.9	3.4	3.9	4.4	4.9	5.5	6.1	6.6
		C	3.2	3.6	4.0	4.5	5.1	5.7	6.3	6.8
		F	1.9	2.0	2.2	2.3	2.5	2.7	3.0	3.3
	Height = 0.6 m	S	2.8	3.4	4.1	4.7	5.1	5.6	6.3	7.0
		C	3.5	3.8	4.2	4.6	5.2	5.8	6.5	7.2
		F	1.9	2.0	2.2	2.3	2.5	2.7	3.0	3.3
	Height > 1.0 m	S	3.2	3.7	4.2	4.7	5.2	5.8	6.5	7.2
		C	3.4	3.9	4.4	4.9	5.4	6.0	6.7	7.4
		F	1.9	2.0	2.2	2.3	2.5	2.7	3.0	3.3
Trees	Diameter = 50 mm	A	0.2	0.3	0.3	0.4	0.5	0.5	0.7	0.8
	Diameter = 100 mm	A	1.0	1.1	1.1	1.2	1.3	1.5	1.7	2.0
	Diameter = 150 mm	A	2.5	2.6	2.6	2.7	2.9	3.0	3.2	3.3
	Diameter = 200 mm	A	3.2	3.5	3.7	4.0	4.3	4.6	5.0	5.4
	Diameter = 250 mm	A	3.2	3.6	4.0	4.5	5.0	5.6	6.2	6.7
	Diameter = 300 mm	A	3.3	3.7	4.1	4.6	5.1	5.7	6.4	7.1

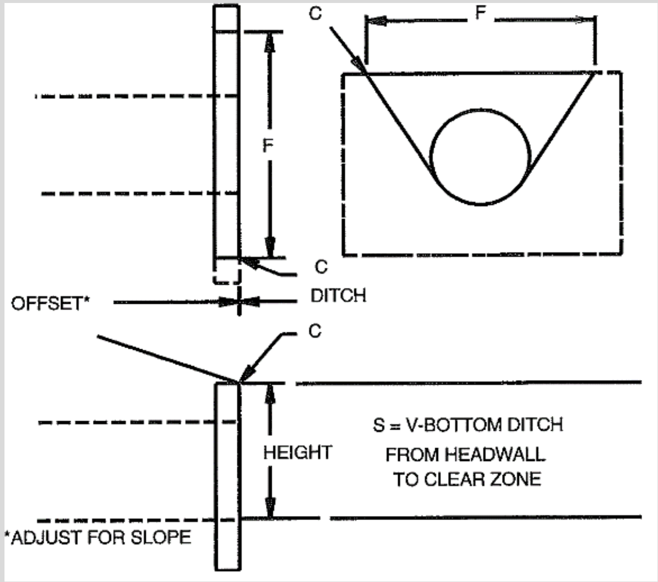
Object type and characteristics		Object surface (*)	Severity index							
			Design speed (km/h)							
			50	60	70	80	90	100	110	120
	Diameter > 300 mm	A	3.4	3.8	4.2	4.7	5.2	5.8	6.5	7.2
Utility poles (wooden)	Diameter = 200 mm	A	3.1	3.4	3.6	3.9	4.2	4.5	4.9	5.3
	Diameter = 250 mm	A	3.1	3.5	3.9	4.4	4.9	5.5	6.1	6.6
	Diameter = 300 mm	A	3.3	3.7	4.1	4.6	5.1	5.6	6.3	7.0
	Diameter > 300 mm	A	3.4	3.8	4.2	4.7	5.2	5.8	6.5	7.2
Break away support with 35 km/h crash test velocity and a change of velocity during the test as shown in the next column	1.5 metres/second	A	0.9	1.0	1.2	1.3	1.4	1.6	1.8	1.9
	3.0 metres/second	A	1.4	1.5	1.7	1.8	1.9	2.1	2.3	2.6
	4.5 metres/second	A	1.8	2.0	2.2	2.4	2.5	2.7	2.9	3.2
	6.1 metres/second	A	2.3	2.5	2.7	2.9	3.1	3.3	3.5	3.8
	7.6 metres/second	A	2.9	3.1	3.3	3.5	3.7	3.9	4.1	4.4

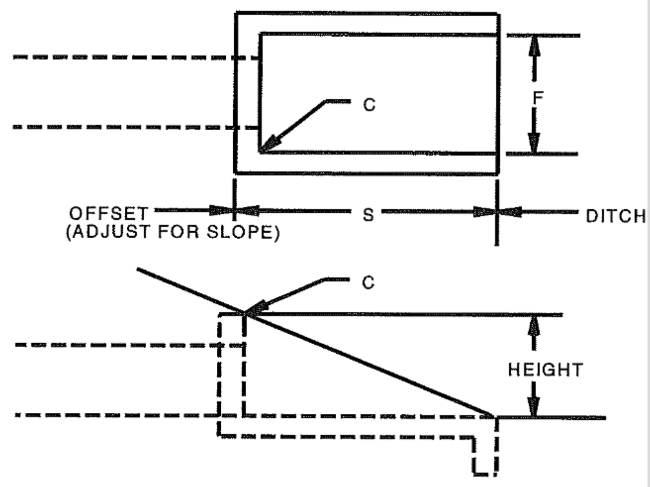
**S = Approach Side, C = Corner, F = Traffic Face, A = S, C, and F.*

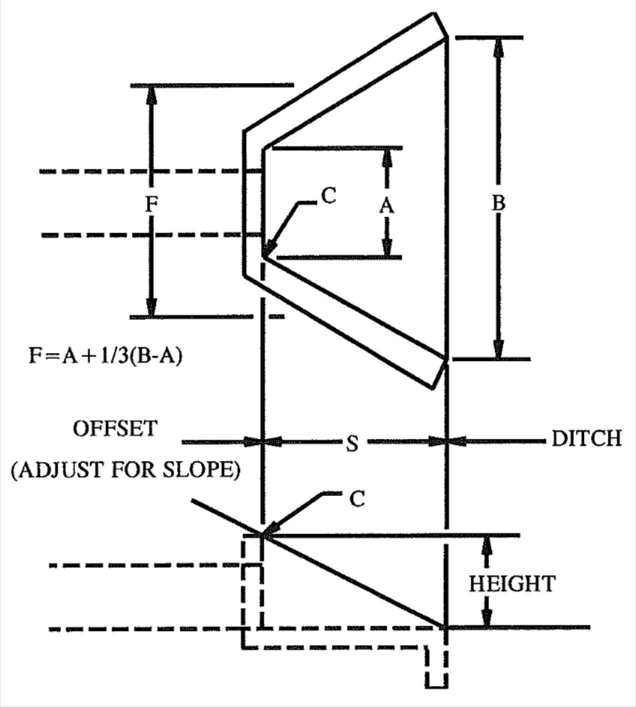
Table E 10: Suggested severity indices – culverts

Object type and characteristics		Object surface (*)	Severity index							
			Design speed (km/h)							
Description	Height		50	60	70	80	90	100	110	120
Culvert ends: Culvert axis transverse to traffic Culvert end type A (See sketch below) 	0.3 m	S	0.4	0.5	0.7	0.8	0.9	1.1	1.3	1.4
		C	1.4	1.7	2.0	2.3	2.7	3.1	3.4	3.7
		F	2.3	2.6	2.9	3.2	3.4	3.7	4.0	4.3
	0.5 m	S	0.6	0.7	0.9	1.0	1.2	1.4	1.6	1.7
		C	1.7	2.1	2.5	3.0	3.4	3.8	4.3	4.8
		F	2.1	2.4	2.8	3.2	3.4	3.6	4.0	4.4
	0.6 m	S	1.5	1.8	2.2	2.6	2.9	3.2	3.6	4.0
		C	1.9	2.5	3.2	3.8	4.3	4.8	5.3	5.8
		F	2.2	2.5	2.8	3.1	3.3	3.6	4.0	4.4
	1.0 m	S	2.1	2.5	2.9	3.4	3.8	4.2	4.7	5.2
		C	2.0	2.6	3.1	3.7	4.3	4.9	5.5	6.0
		F	2.2	2.5	2.8	3.1	3.5	3.8	4.1	4.4
	1.2 m	S	2.6	3.0	3.4	3.9	4.3	4.8	5.4	5.9
		C	1.6	2.2	2.9	3.5	4.2	4.8	5.4	6.1
		F	2.1	2.5	2.9	3.4	3.8	4.1	4.3	4.6
	1.8 m	S	2.9	3.3	3.7	4.2	4.7	5.2	5.8	6.5
		C	1.1	1.8	2.5	3.2	3.9	4.5	5.1	5.8
		F	1.6	2.1	2.6	3.1	3.4	3.8	4.2	4.6
	2.4 m	S	3.0	3.5	4.0	4.5	5.0	5.6	6.2	6.7
		C	0.2	1.0	1.9	2.7	3.4	4.1	4.7	5.4
		F	1.5	1.9	2.3	2.8	3.3	3.7	4.1	4.5

Object type and characteristics		Object surface (*)	Severity index							
			Design speed (km/h)							
Description	Height		50	60	70	80	90	100	110	120
Culvert ends: Culvert axis transverse to traffic (contd.) Culvert end type B (See sketch below)  	0.3 m	S,C,& F	0.2	0.3	0.5	0.6	0.8	1.0	1.3	1.6
	0.5 m	S,C,& F	0.4	0.5	0.7	0.8	1.2	1.6	2.0	2.4
	0.6 m	S,C,& F	0.3	0.6	0.9	1.2	1.7	2.1	2.3	2.6
	1.0 m	S,C,& F	0.5	1.0	1.5	2.0	2.3	2.6	3.0	3.4
	1.2 m	S,C,& F	1.5	1.8	2.1	2.4	2.8	3.2	3.6	4.0
	1.8 m	S,C,& F	1.9	2.3	2.7	3.2	3.7	4.1	4.5	4.9
	2.4 m	S,C,& F	2.5	2.9	3.3	3.8	4.3	4.8	5.3	5.8

Object type and characteristics		Object surface (*)	Severity index							
			Design speed (km/h)							
Description	**Height**		**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**
Culvert ends: Culvert axis transverse to traffic (Contd.) Culvert end type C (See sketch below) 	0.3 m	C,S	2.4	2.7	3.0	3.3	3.6	3.9	4.3	4.7
		F	2.1	2.4	2.7	3.0	3.3	3.6	3.8	4.1
	0.5 m	C,S	3.0	3.3	3.5	3.8	4.1	4.4	4.6	4.9
		F	2.6	2.9	3.1	3.4	3.6	3.9	4.1	4.4
	0.6 m	C,S	3.2	3.5	3.8	4.1	4.4	4.7	5.0	5.3
		F	2.8	3.1	3.3	3.6	3.8	4.1	4.3	4.6
	1.0 m	C,S	3.9	4.2	4.5	4.8	5.0	5.3	5.5	5.8
		F	3.0	3.3	3.6	3.9	4.1	4.4	4.6	4.9
	1.2 m	C,S	4.3	4.5	4.7	4.9	5.2	5.5	5.8	6.1
		F	3.5	3.7	3.9	4.1	4.3	4.6	4.8	5.1
	1.8 m	C,S	4.8	5.0	5.2	5.4	5.7	6.0	6.3	6.6
		F	4.0	4.2	4.4	4.6	4.8	5.1	5.3	5.6
	2.4 m	C,S	5.2	5.4	5.6	5.8	6.0	6.3	6.6	6.9
		F	4.6	4.7	4.9	5.0	5.2	5.5	5.7	6.0

Object type and characteristics		Object surface (*)	Severity index							
			Design speed (km/h)							
Description	**Height**		**50**	**60**	**70**	**80**	**90**	**100**	**110**	**120**
Culvert ends: Culvert axis transverse to traffic (cont.) Culvert end Type D (See sketch below) 	0.3 m	S,C,& F	1.2	1.4	1.6	1.8	2.0	2.3	2.6	2.9
	0.5 m	S,C,& F	1.5	1.7	1.9	2.1	2.4	2.8	3.5	4.2
	0.6 m	S,C,& F	1.6	1.9	2.1	2.4	2.8	3.1	3.3	3.6
	1.0 m	S,C,& F	1.7	2.1	2.5	3.0	3.2	3.5	3.8	4.1
	1.2 m	S,C,& F	2.4	2.7	3.0	3.3	3.6	3.9	4.2	4.5
	1.8 m	S,C,& F	3.0	3.3	3.6	3.9	4.3	4.6	4.9	5.2
	2.4 m	S,C,& F	3.3	3.6	4.0	4.4	4.8	5.1	5.5	5.9

Object type and characteristics		Object surface (*)	Severity index							
			Design speed (km/h)							
Description	Height		50	60	70	80	90	100	110	120
Culvert ends: Culvert axis transverse to traffic (cont.) Culvert end type E (See sketch below)  	0.3 m	S	1.8	2.1	2.3	2.6	2.9	3.1	3.3	3.4
		C	2.2	2.5	2.8	3.1	3.4	3.7	3.9	4.2
		F	1.8	2.0	2.2	2.4	2.7	3.0	3.2	3.3
	0.5 m	S	2.5	2.7	2.9	3.1	3.2	3.4	3.7	4.0
		C	3.0	3.2	3.4	3.6	3.8	4.1	4.3	4.6
		F	2.3	2.5	2.7	2.9	3.1	3.3	3.5	3.8
	0.6 m	S	2.6	2.8	3.0	3.2	3.4	3.7	4.0	4.3
		C	3.0	3.3	3.5	3.8	4.3	4.0	4.6	4.9
		F	2.3	2.6	2.8	3.1	3.3	3.5	3.8	4.1
	1.0 m	S	2.7	3.0	3.4	3.8	4.0	4.2	4.4	4.5
		C	3.3	3.6	4.0	4.4	4.6	4.8	5.0	5.3
		F	2.7	3.0	3.3	3.6	3.8	4.0	4.2	4.3
	1.2 m	S	3.3	3.5	3.7	3.9	4.1	4.3	4.6	4.9
		C	3.9	4.1	4.3	4.5	4.7	5.0	5.3	5.6
		F	3.1	3.3	3.5	3.7	3.9	4.1	4.4	4.7
	1.8 rn	S	3.9	4.0	4.2	4.3	4.5	4.8	5.1	5.4
		C	4.4	4.6	4.8	5.0	5.2	5.5	5.8	6.1
		F	3.7	3.8	4.0	4.1	4.3	4.6	4.9	5.2
	2.4 m	S	4.3	4.4	4.6	4.7	4.9	5.1	5.2	5.2
		C	5.0	5.1	5.3	5.4	5.6	5.8	6.0	6.1
		F	4.1	4.2	4.4	4.5	4.7	4.9	5.0	5.0

**S = Approach Side, C = Corner, F = Traffic Face, A = S, C, and F.*

Note: The ditch beyond the culvert end is also an obstacle and should be accounted for in an economic analysis and in locating safety barrier.

Appendix F Example of Manual Calculation of Run-off-Road Crash Numbers and Costs

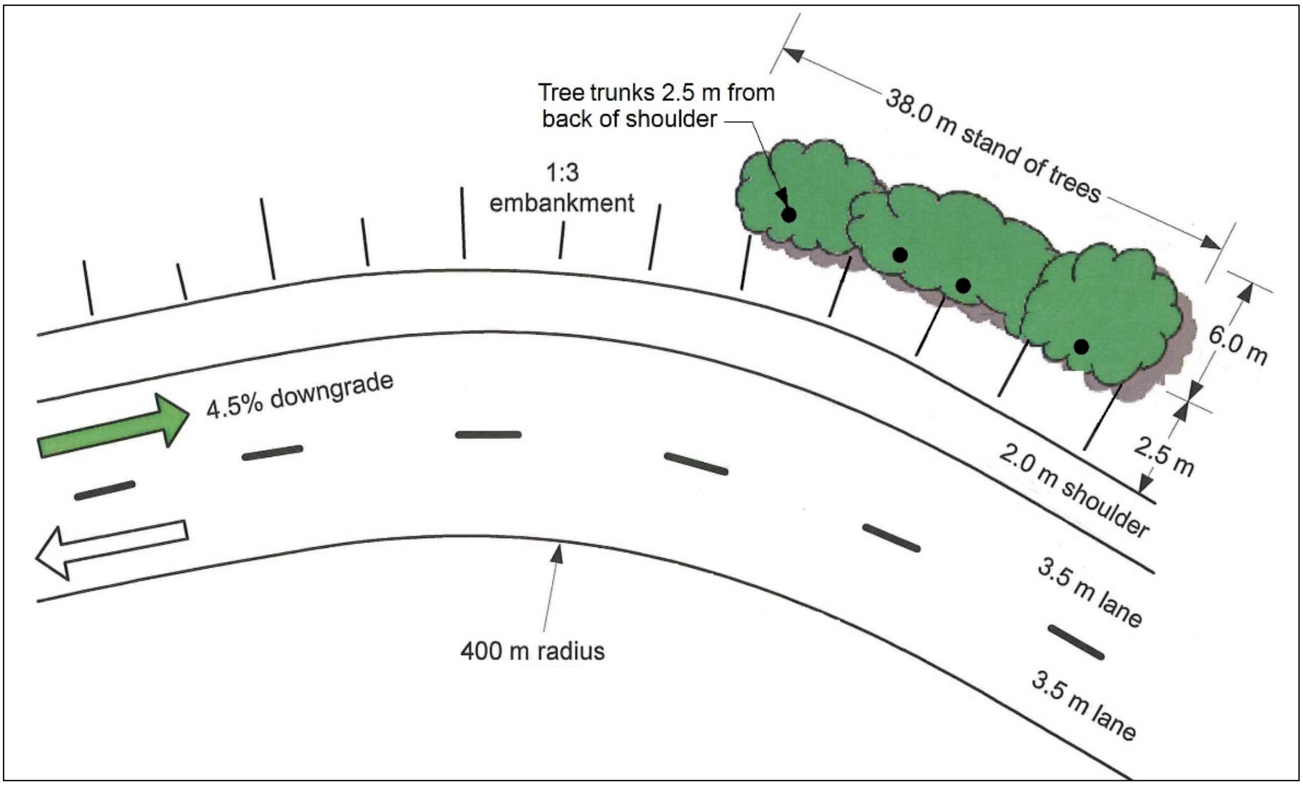
F.1 Example

This appendix provides an example of crash cost calculations for input to a detailed manual quantitative evaluation of a hazard and a treatment option. The formula for this calculation is provided in Section 4.6.2. The example in Figure F 1 shows a 2.0 m wide shoulder and a 3:1 batter with 450 mm tree trunks at the toe of the batter, the land beyond the toe sloping at 6:1. The 3:1 batter does not contribute to the clear zone distance and therefore for the purpose of calculation the clearance to the tree trunks must be taken as 2.0 m. The AADT is 2500 and the operating speed of the road is 80 km/h. Crash records indicate that there are no reported crashes at the site and therefore an analysis based on risk is undertaken to assess the need for treatment.

F.2 Run-off-road Crashes into Hazard

Referring to Table 4.1 and Table 4.2 for eastbound traffic the required theoretical clear zone is 6.5 x 1.3 = 8.45 m. As the 3:1 batter does not aid recovery the clear zone would extend to a point 8.45 + 2.5 = 10.95 m from the edge of traffic lane, which is beyond the hazardous tree trunks. For westbound traffic the clear zone would also be 8.45 m. As the 3:1 batter does not aid recovery the clear zone would extend to a point 10.95 m from the centreline of the road. As the tree trunks are about 8.0 m from the centreline they are a hazard for westbound traffic as well.

Figure F 1: Example of hazard for calculating encroachment run-off-road rate



Source: Adapted from RTA (2008).

R1 – Calculate the frequency of errant vehicle crashes

Frequency of errant vehicle crashes $N = \frac{(E_Q GR) P_h P_i}{278}$

Data and calculations for example – Eastbound.

Table F 1: Data for calculations

Variable	Description	Eastbound	Westbound
Q	Traffic volume	AADT = 1250 vpd	AADT = 1250 vpd
E_Q	Encroachment run-off-road rate	From Figure 4.11 for an AADT of 1250 vpd, E_Q = 1.0	E_Q = 1.0
G	Grade – 4.5% downgrade	From Table 4.6 interpolate for adjustment = 1.625	+4.5% Grade adjustment = 1.0
R	400 m curve hazard on outside	From Table 4.7 adjustment = 2.7	2.7
P_h	Probability that hazard present	A hazard has been identified (Section 4.2.4). Therefore probability =1.0	1.0
P_i	Probability that errant vehicle will reach hazard	Because of the steep 3:1 batter the recovery area is only the width of the shoulder and hence the distance from the edge of the travelled way for use in Figure 4.12 is 2.0 m. From Figure 4.12, for this undivided road P_i = 0.60.	Distance to hazard = 5.5 m to top of 3:1 batter P_i = 0.23.

Therefore $N_{Eastbound}$ = (1.0 x 1.625 x 2.7) 1.0 x 0.60/278 = 0.010 crashes/year at the site,

and $N_{Westbound}$ = (1.0 x 1.0 x 2.7) 1.0 x 0.23/278 = 0.002 crashes/year at the site.

For both directions the number of crashes into the hazard = 0.012 per year at the site (over a 3.6 m swath width as the factor of 278 is derived from 1 km/3.6 m).

Therefore, total crashes into hazard at the site = (38 x 0.012)/3.6 = 0.127 crashes/year at the site.

F.3 Options for Treatment

If the trees have no significance in terms of their condition, species or as a habitat for fauna and there is sufficient space in the road reservation, then the preferred treatment would be to remove the trees and flatten the embankment. If the road reservation is wide enough the trees could be replaced outside the clear zone either at the same site or at another location along the road.

If the trees are valued for retention at the site then a road safety barrier system may be considered. The length of need of the safety barrier determined graphically by the angle of departure method would be about 82 m and allowing for terminals would be say 97 m long.

As the safety barrier would have to be located coincident with the back of the shoulder the application of the formula in Section F.2 would yield the same rate of crashes into the safety barrier (because the non-recoverable 3:1 batter does not contribute to clearance to the hazard in this case). However, the barrier would have more crashes due to the increased length of hazard (i.e. 97 m instead of 38 m).

Total crashes into the safety barrier = 0.012 crashes per year (over a 3.6 m swath width).

Therefore, total crashes into barrier at the site = (97 x 0.012)/3.6 = 0.323 crashes/year at the site.

The benefit in providing a safety barrier would therefore be to reduce the severity of the crashes. From Table E 9 in Appendix E for a speed of 80 km/h a tree ≥ 300 mm diameter has a severity index of 4.7 whereas a road safety barrier (e.g. W-beam) has a severity index of 2.3 (refer to Table E 8).

Table 4.8 shows an example of costs of crashes related to the severity index. It should be noted that the costs are not up to date and are provided as an example only. Designers should obtain appropriate costs from the relevant jurisdiction. Interpolating from the table indicates that a crash into the hazardous trees is likely to have a cost, on average for all crash severities (i.e. fatal, moderate injury etc.), of about $200,000 whereas a crash into the barrier is likely to have a cost of about $20,000. Therefore the total cost of crashes into the:

- hazard = 0.127 x $200,000 = $25,400 per year
- barrier = 0.323 x $20,000 = $6,460 per year.

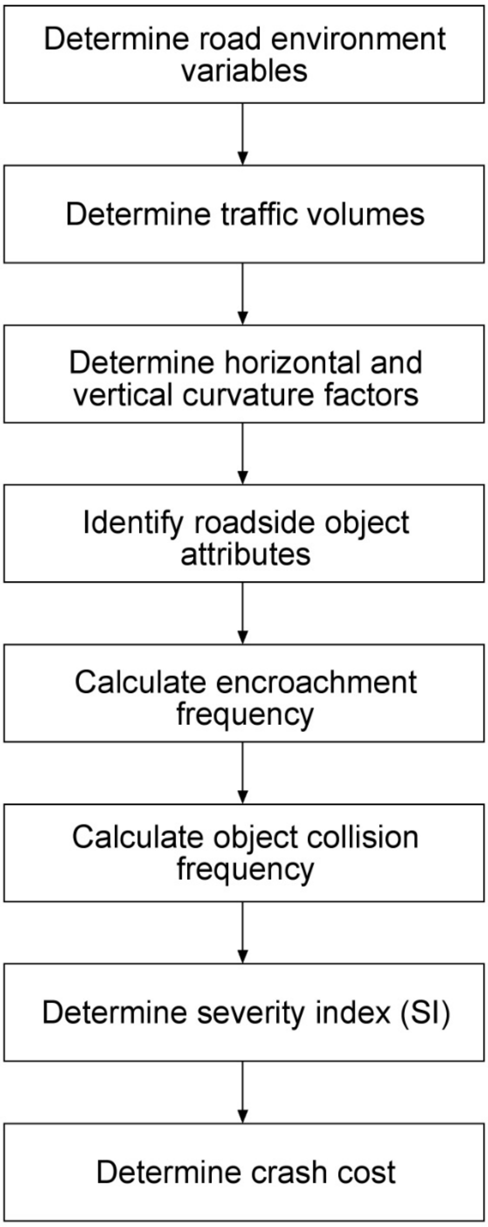
It can be seen that although the barrier would experience more crashes than the hazard, the annual crash costs are significantly less because of the reduced severity of the barrier crashes compared to the trees. These annual crash costs, together with all other costs associated with the installation and maintenance of a barrier should be used in a benefit-cost analysis to assist a designer to decide on the most appropriate action to recommend.

Appendix G RISC Method and Process

G.1 Roadside Impact Severity Calculator (RISC)

The RISC method and process is illustrated in Figure G 1 and described below. It determines the crash frequency for objects and calculates annual crash costs based on the likely severity of impacts. These crash costs can be used as the basis for an economic analysis described in Section 4.5.2.

Figure G 1: Flowchart of risk assessment process used in RISC



Source: QDMR (2005).

G.1.1 Determine Road Environment Variables

Road environment variables define the roadway characteristics and are used to determine the base encroachment frequency (the number of expected encroachments per kilometre per year).

The following variables are required:

- road type – the three general road types are divided, undivided and one-way
- number of lanes – the number of lanes on each carriageway
- width of lanes – the width of the marked lanes
- 85th percentile speed – if unavailable then the posted limit can be used.

G.1.2 Determine Traffic Volumes

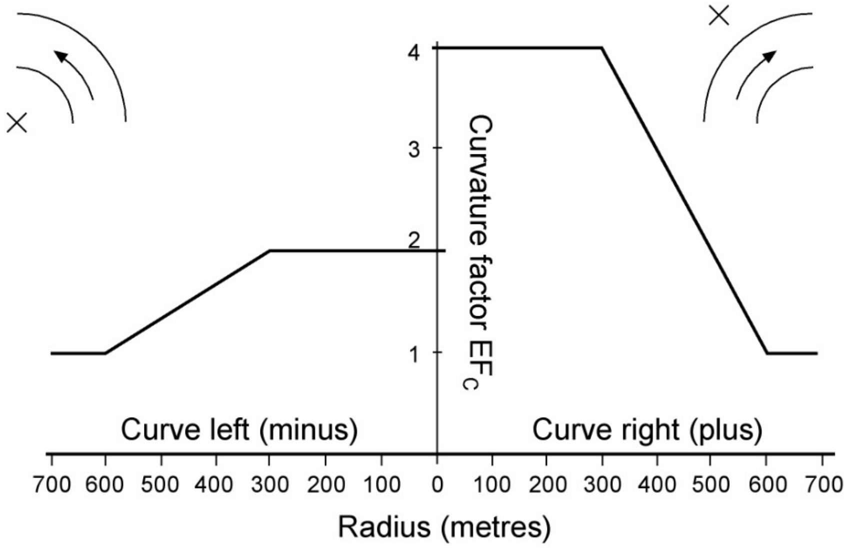
The current traffic volume of the road can be determined from traffic survey counts.

The traffic volume is then divided into the number of carriageways. For example, on a two-lane two-way road, the traffic volume would remain unchanged (i.e. it is a single carriageway), whereas for a four-lane divided facility, the volume is divided by two. If a split of traffic other than 50/50 is evident, then the traffic volumes can be proportioned to each carriageway accordingly.

G.1.3 Determine Curvature and Grade Factors

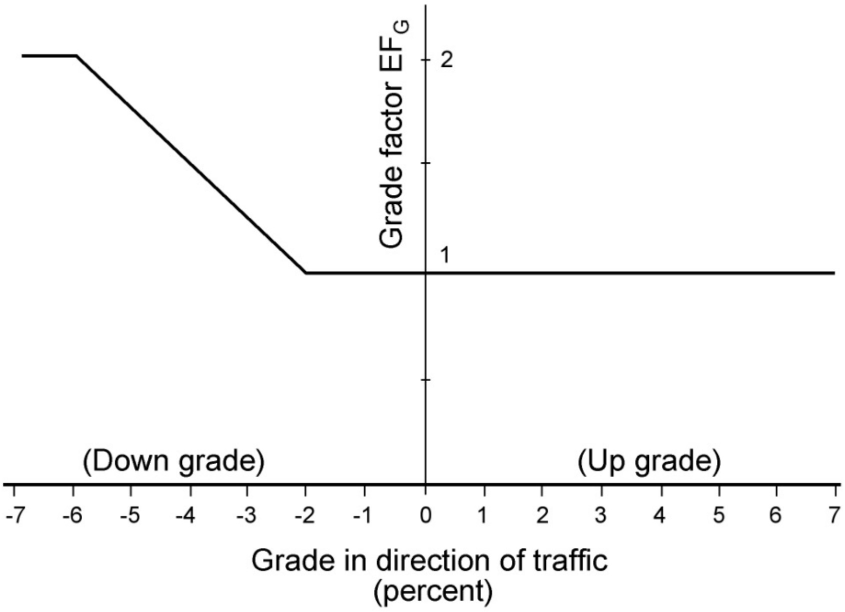
Figure G 2 and Figure G 3 provide adjustment factors for road curvature (EF_c) and for longitudinal grade (EF_g) respectively. These figures modify the encroachment frequency, due to the increased probability of a vehicle leaving the road on horizontal curves or grades.

Figure G 2: Horizontal curve correction factors (EF_C)



Source: QDMR (2005).

Figure G 3: Grade correction factors (EF_g)



Source: QDMR (2005).

G.1.4 Identify Roadside Object Attributes

The following attributes, in combination with vehicle speed and road curvature, define the probability of impact with the object:

- horizontal offset of object from the edge of the travelled way
- object length
- object width.

G.1.5 Calculate Encroachment Frequency

The likelihood of a vehicle leaving the roadway under particular circumstances is then determined using the following relationship:

$$EF = (BER)(AADT)(EF_C)(EF_G)(EF_U)$$

where

EF = encroachment frequency (encroachments/year/km)

BER = base encroachment rate (enc/km/year/vpd) (refer to QDTMR guidelines)

AADT = annual average daily traffic

EF_c = curvature factor (refer to Figure G 2)

EF_g = grade factor (refer to Figure G 3)

Ef_u = user factor (used at discretion of engineer to accommodate special circumstances)

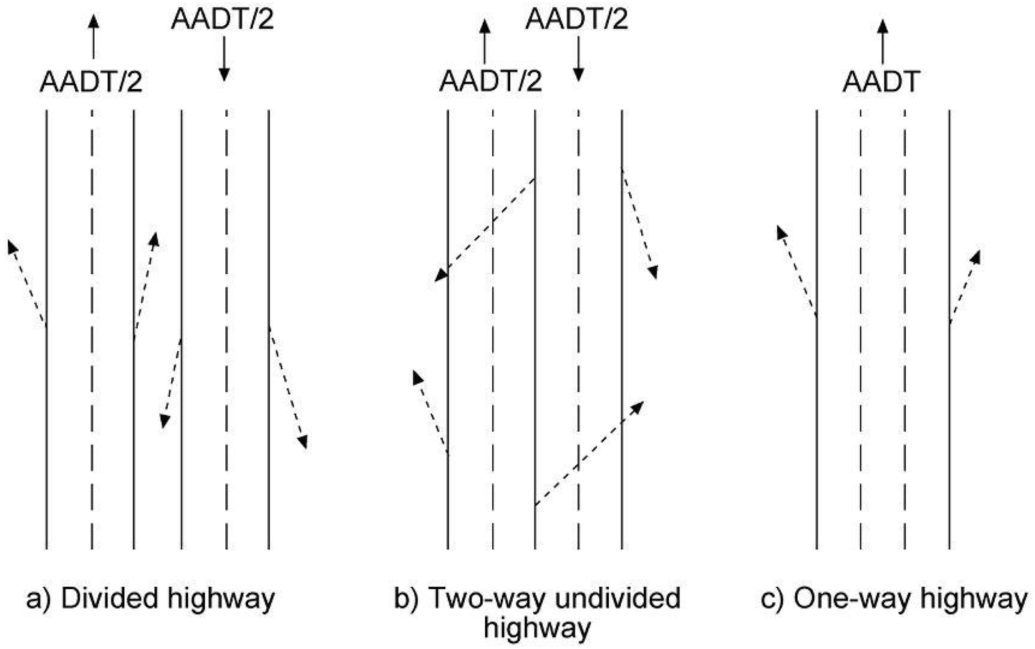
The encroachment frequency is an estimation of the number of vehicles that will leave the roadway per kilometre per year. Clearly not all vehicles that leave the roadway will necessarily collide with a roadside object and variables such as the object's size, offset from the carriageway and vehicle speed influence the likelihood of impact with the object.

The base encroachment rate is based on work performed in the United States, outlined in the American Association of State Highway and Transportation Officials *Roadside Design Guide* (AASHTO 1996). This rate should be adjusted when actual data at a specific location is available, or modified based on engineering judgement for non-typical conditions.

G.1.6 Calculate Object Collision Frequency

The number of impacts for any object is dependent upon the number of directions from which it can be impacted. For example, an object on the left-hand side of a divided road can only be struck from one direction of travel, whereas an object in the median can potentially be struck from traffic travelling in either direction. Figure G 4 depicts the three typical types of roadway classifications from this perspective.

Figure G 4: Typical roadway types



Source: QDMR (2005).

Using the encroachment frequency determined in Section G.1.5 and the attributes of the object being analysed (refer to Section G.1.4) an estimate of the number of impacts per year with the object can be determined.

To estimate the object collision frequency the impact zones of the object are divided into three areas, upstream face (zone 1), corner (zone 2) and parallel face (zone 3), as shown in Figure G 5.

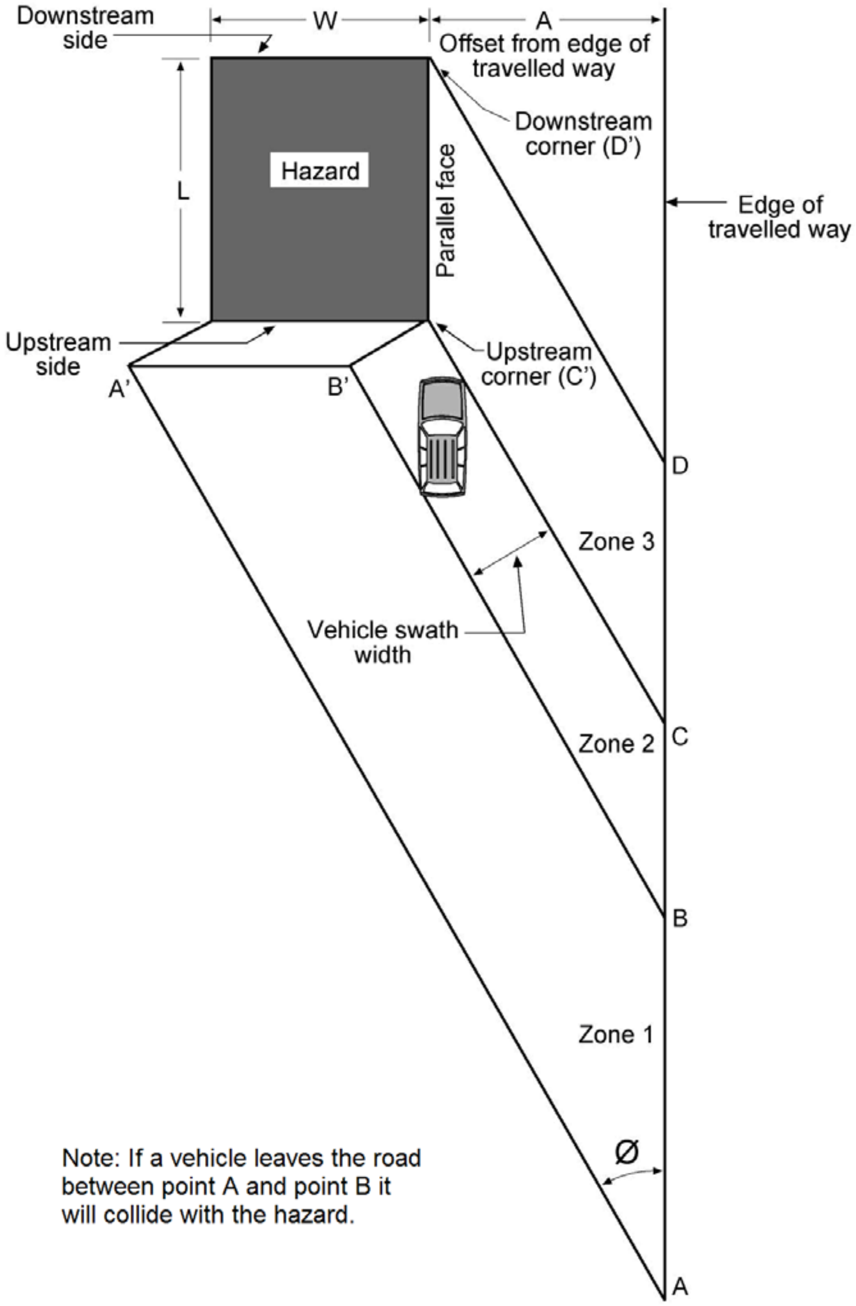
For the situation where the object can only be impacted from one direction, the following cases apply:

- collision frequency for upstream side (zone 1)
- collision frequency for upstream corner (zone 2)
- collision frequency for parallel face (zone 3).

Whereas, if the object can also be impacted from the opposing direction the following cases must be calculated:

- collision frequency downstream side (zone 1)
- collision frequency downstream corner (zone 2)
- collision frequency for parallel face (zone 3).

Figure G 5: Impact zones for rigid roadside objects



Note: If a vehicle leaves the road between point A and point B it will collide with the hazard.

Source: QDMR (2005).

Note that for the opposing direction, the lateral offset of the object may need to be increased given that there is at least an additional lane between the object and the travelled path. While the following equations are complicated, software such as the RISC program obviates the need for time consuming manual analysis.

$$CFUS = (EF)(\frac{1}{\tan\phi})\left[\sum_{i=1}^{W} LEP(A + SW\cos\phi + |i-1|)\right]/1000$$

$$CFUC = (EF)(\frac{1}{\sin\phi})\left[\sum_{i=1}^{W} LEP(A + |i-1|\cos\phi)\right]/1000$$

$$CFFA = (EF)(L)LEP(A)/1000$$

where

CFUS = collision frequency for the upstream side

CFUC = collision frequency for the upstream corner

CFFA = collision frequency for the parallel face

LEP = lateral extent probability

f = encroachment angle (degrees)

SW = swath width (3.6 m)

EF = encroachment frequency (enc/km/y)

A = lateral offset of object (m)

W = width of object (m).

When determining the impacts for traffic travelling in lanes other than the lane closest to the hazard (e.g. traffic travelling in the opposite direction), it is important to increase the offset of the feature to reflect the increased distance to the travel lane. The variable (A) is replaced with:

A+ (number of adjacent lanes) x (lane width)

The total number of impacts per year for the object is given by:

$$IMPACTS/YEAR = CFUS + CFUC + CFFA$$

G.1.7 Determine Severity Index (SI) for Object

Once the collision frequency has been calculated for the roadside object, it is necessary to assign severity values. As discussed earlier, the severity index defines the severity of the outcome of an impact with a particular roadside feature. Tables in Appendix E provide suggested severity indices for particular features and various design speeds. Other jurisdictions may have a different system, for example, the Queensland Department of Transport and Main Roads has a detailed matrix of severity indices for use in the RISC program. It is important to note that the values in Appendix E are a guide and engineering judgement may be applied to determine appropriate values for particular situations.

A separate severity index for each impact zone of the hazard should be applied. This process is automated when software such as RISC is used.

G.1.8 Determine Crash Costs

Once the number of crashes that can be expected at a given location and the object's severity index is known, the expected crash cost per year can be calculated using the following relationship shown in italics below. Table 4.8 shows an example of typical costs of crashes related to the severity index. The costs are based on a vehicle occupancy of one person and the proportion of crash outcome types. However, the costs are not suitable for analysis on projects and designers should obtain the appropriate costs from the relevant jurisdiction.

Annual crash costs per year ($) = (impacts per year) x (SI crash cost per impact)

In this relationship 'impacts per year' is the collision frequency calculated in Section G.1.6 and the severity index (SI) crash cost per impact is obtained from relevant jurisdictional information (see example in Table 4.8). This information should then be used as input to an economic analysis as described in Section 4.5.2.

Appendix H Treatments for Brownfield Sites

H.1 Treatments for Roads

H.1.1 Treatments for Pavement Edge Drop-off

Pavement edge drop-offs can lead to loss of vehicle control under certain circumstances, where inattentive or inexperienced drivers return to the traffic lane by oversteering to overcome the resistance from a continuous pavement edge and tyre-scrubbing condition. This can result in drivers crossing the opposing traffic stream sometimes with disastrous consequences.

Pavement edge drop-offs can occur during highway repair or resurfacing work. When not properly addressed, drop-offs can lead to loss of vehicle control with a high potential for a serious crash.

Pavement edge drop-offs can be rectified by edge patching or sealing of shoulders.

H.1.2 Treatments for Opposing Vehicles

Where the opposing lane or lanes are within the area of interest, there is a danger of collision with other vehicles, especially oncoming vehicles. In this case all available treatment options should be considered including the following options:

- Provide sufficient median width to place the opposing carriageway outside the area of interest.
- Provide a road safety barrier in the median.
- Where traffic flows warrant only a two-lane, two-way road it may not be possible to introduce a central median. In this situation ensure the roadside is free of hazards so vehicles can take evasive action if an opposing vehicle crosses the centre of the road.
- However, in some instances it may be possible to provide a narrow painted median to increase the separation or a road safety barrier in a narrow median (Figure H 1).

Figure H 1: Wire rope barrier in a narrow median on a sharp bend

H.2 Treatments for Bridges

H.2.1 General

The structural limitations of old bridges often prevent upgrade of their barriers to current standards. Engineering expertise and judgement must be used to design the best possible upgrade if a risk assessment shows that the existing barrier has an unacceptable risk. The reasons for not meeting current standards need to be well documented and justified.

If the bridge and its barriers present a very high risk, and upgrade is not structurally possible, it may be necessary to program the replacement of the bridge.

H.2.2 Treatments for Bridge Piers, Abutments, End Posts and Tunnel Portals

Bridge ends should be designed to prevent vehicles from running into end support posts, being speared by any horizontal bridge members or simply crashing through any approach barrier and being exposed to a hazard (e.g. rollover, railway track, water course).

Stiffening needs to be provided on the transition from the semi-rigid approach barrier to the rigid bridge structure, otherwise the excessive local deformation will cause errant vehicles to snag on the end of the bridge barrier.

The piers of bridges over roads (at overpasses) should desirably be protected by a crash cushion or road safety barrier. It may be necessary to provide a barrier that can shield piers from heavy vehicle crashes which may involve a two-stage protection system (Figure 6.19).

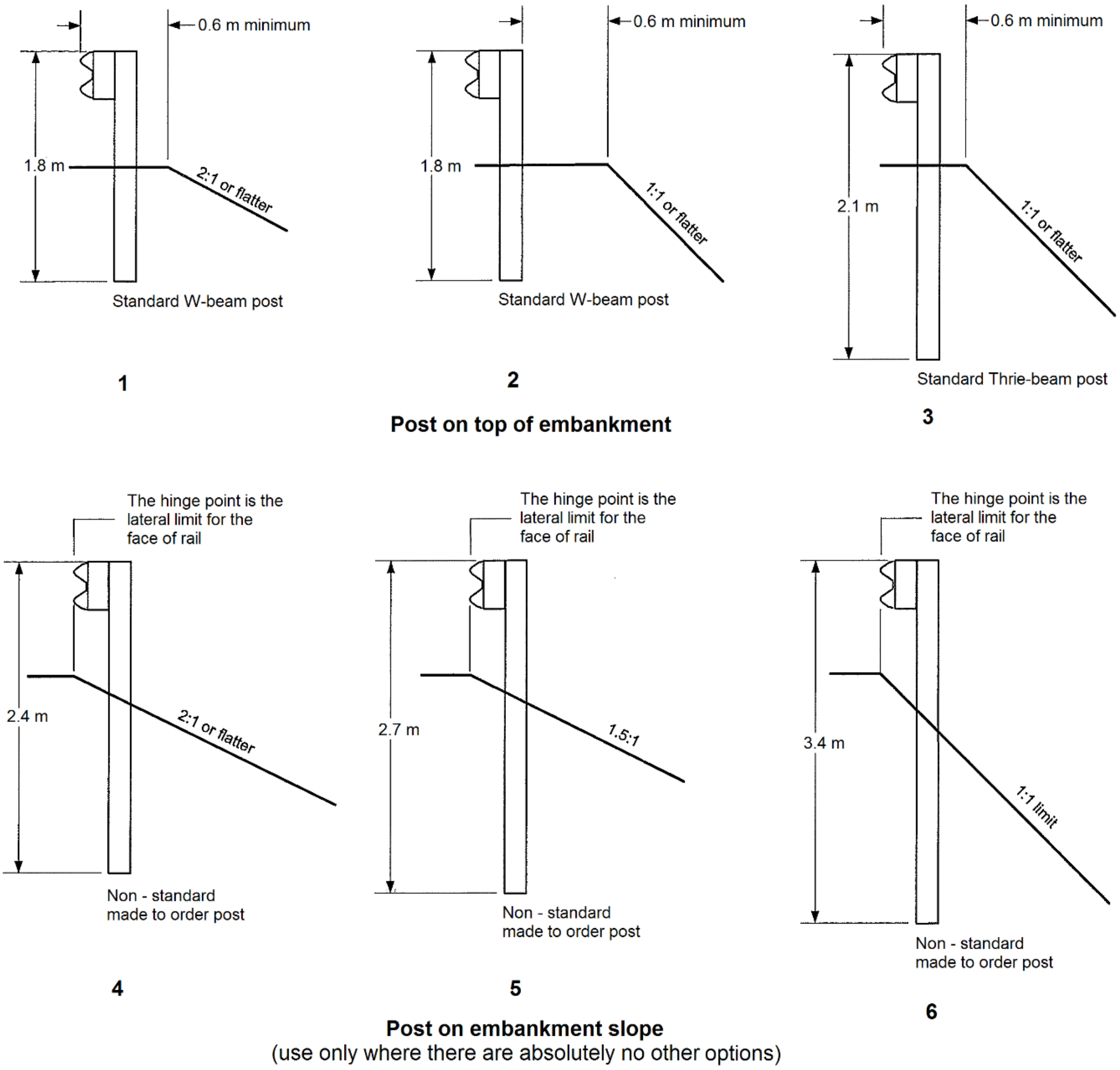
H.3 Barrier Placement in Constrained Situations

H.3.1 Location on Embankments

Road safety barriers perform best on slopes flatter than 10:1 (10% maximum crossfall). Barriers should not be placed on embankments steeper than 6:1. On steep embankments, the vehicle trajectory may impact the barrier too high and cause the vehicle to launch. Vehicle trajectory on embankments and cut batters is discussed and illustrated in Commentary 12.

The hinge point of batters steeper than 4:1 should be located outside the deflection width of the road safety barrier. In low-speed areas with constrained formation widths (e.g. existing mountain passes) the post locations shown in Figure H 2 (WSDOT 2009) may be necessary but should only be adopted where there are no other options.

Figure H 2: Barrier post location on constrained sites



The offset to the hinge point should be greater than the offset to limit of deflection for batters steeper than 3:1.
The offset to the hinge point may be reduced as shown where there are absolutely no other options.

Source: Based on WSDOT (2009).

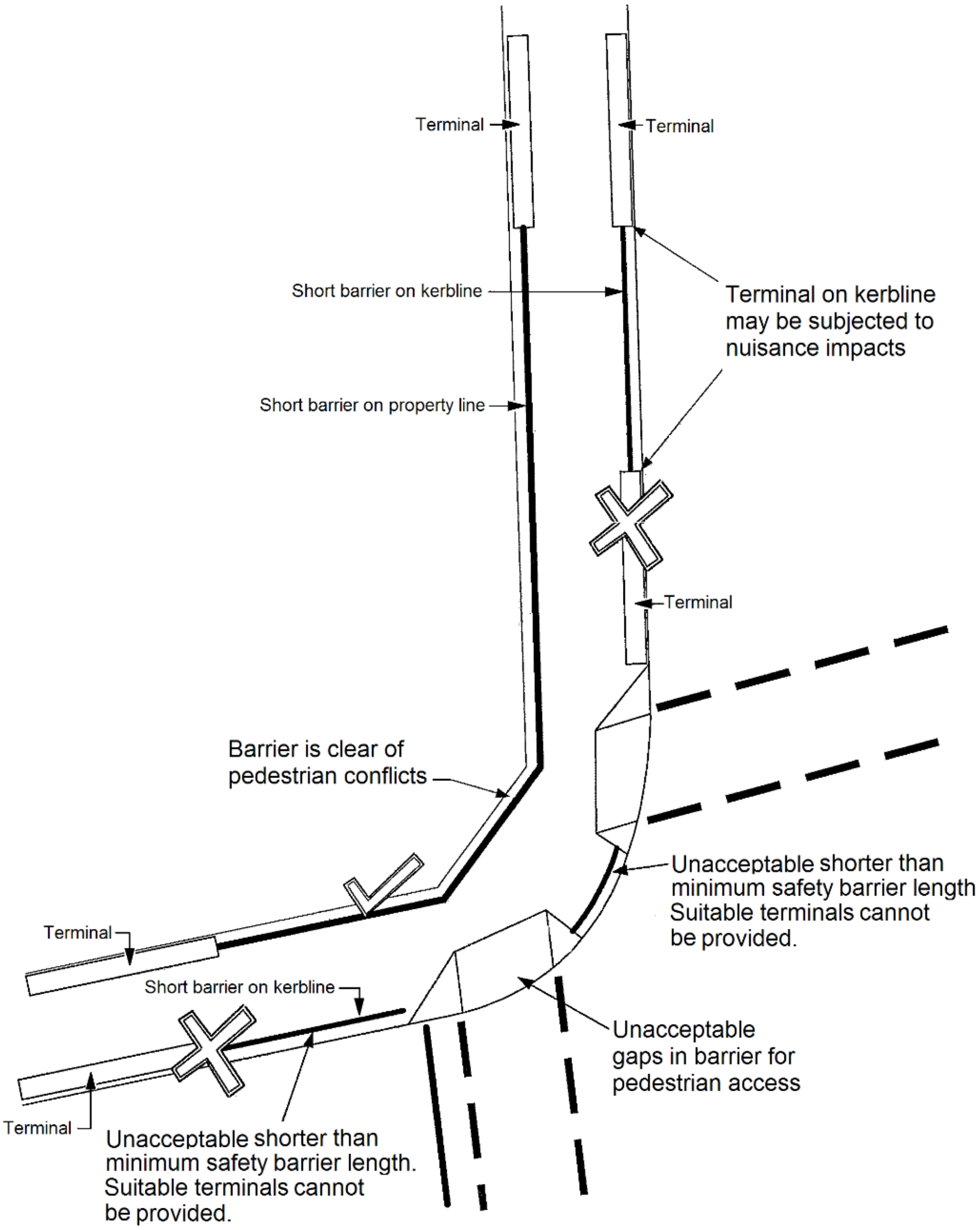
H.3.2 Location on Urban Footway Corners

It is generally preferable that barriers are not provided on urban footway corners to protect pedestrians because:

- the encroachment of errant vehicles at these locations is a relatively rare event
- it is necessary to provide openings in the barrier for pedestrian movement and difficult to accommodate safe end treatments (which are very expensive)
- the short lengths of barrier that invariably result are too short to develop the required strength and operate as intended when impacted.

Where it is necessary to install a barrier to shield a vulnerable site (e.g. childcare centre) it is preferable to locate the road safety barrier on the fence line rather than over the kerb. This will avoid the problem of shorter than minimum road safety barrier lengths, lack of terminals, locating a terminal on the kerb line, conflict of posts with drainage conduits and avoid problems with pedestrian access across the barrier, as shown in Figure H 3.

Figure H 3: Road safety barriers on footway corners



Source: Based on RTA (2008).

H.4 Wire Rope Barrier in Narrow Medians

The use of wire rope barrier in the centre of narrow medians is a relatively new practice. As mentioned previously it is preferable to contain the dynamic deflection within the median. However, it may be appropriate to allow partial encroachment of the deflected barrier into the opposing traffic lane. Table H 1 lists the effects that a centrally located wire rope safety barrier will have after impact for various median widths and which should be considered if a wire rope barrier is proposed for a narrow median.

Table H 1: Issues for wire rope road safety barriers located centrally in medians

Median width	Consequences of 1.7 m deflection at 100 km/h	Debris after impact on 200 m curve
2.8 m	Deflection will encroach 0.3 m into opposing carriageway.	Bent posts and cables lie within median.
2.0 m	Deflection will encroach 0.7 m into opposing carriageway.	Bent posts and cables lie within median.
1.6 m	Deflection will encroach up to 0.9 m into opposing carriageway.	Bent posts lie within median. Cables may lie on edge of carriageway.

Containment of deflections within the median will influence the width of the median to be provided. The Roads and Traffic Authority of New South Wales considers that 1.6 m is the minimum median width for installation of wire rope barriers as the half-median width of 0.8 m is generally sufficient to contain dislodged cables and bent posts from damaged installations.

The cables of a severely impacted wire rope barrier system form a chord across the inside of a curve because the cables are released from the supporting posts. Tests at 80 km/h and 25° impact angle on a 200 m radius curve show that the cables will lie about 0.8 m off the line of the barrier after impact and may become a hazard for oncoming traffic. It is likely that this offset would be larger at higher impact speeds due to dislodgement of longer lengths of wire rope.

The deflection of a wire rope barrier may be greater than the width of the median, which means that the impacting vehicle may encroach onto the opposing carriageway. A crash test on a 200 m radius curve at 80 km/h impact speed and 25° angle of impact showed the 1500 kg vehicle was past the original line of the barrier for about 1.5 seconds, after which the vehicle would be back in the travel lane (RTA 2003). The probability of a collision due to running off the road after impact is related to the probability of a vehicle being adjacent to the impact site during this short period.

Appendix I Examples of Length of Need Calculations

I.1 General

The two methods currently used in Australasia for determining the length of road safety barrier required to shield a hazard are presented in Section 6. The American Association of State Highway and Transportation Officials (AASHTO 2006) suggests the use of the run-out length method for determining the length of need of a road safety barrier and acknowledges that some jurisdictions choose to use an alternative method based on the vehicle angle of departure from the road.

In Australia and New Zealand jurisdictions may use either the run-out length method or the angle of departure method. Each example in this appendix is calculated using both methods.

I.2 Run-out Length Method

This method is presented in Section 6.3.19 and figures, tables and formulae are reproduced below for convenience with respect to the examples provided. Application of the run-out length method to establish road safety barrier length of need for both traffic in the adjacent lane, and for opposing traffic, is illustrated in Figure I 1. On a two-lane two-way road, and for medians, these requirements are combined to develop a design layout that protects traffic from both directions.

The layout of road safety barriers on straight or nearly straight sections of road is established by applying the following formulae. Dimension ‘X’ is the required length of need in advance of the (hazard) and can be calculated from the following equations.

For installations where the road safety barrier is flared (refer to Section 6.3.19):

$$X = \frac{\left[L_A + \left(\frac{b}{a}\right)(L_1) - L_2\right]}{\left[\left(\frac{b}{a}\right) + \left(\frac{L_A}{L_R}\right)\right]}$$

For parallel installations that have no flare:

$$X = \frac{[L_A - L_2]}{\left[\frac{L_A}{L_R}\right]}$$

The lateral offset, Y, from the edge of the running lane to the beginning of the length of need may be calculated from:

$$Y = L_A - \frac{L_A}{L_R}(X)$$

where

X = the required length of need in advance of the hazard

L_R = run-out length (refer to Table 6.9)

b/a = flare rate (refer to Table 6.5)

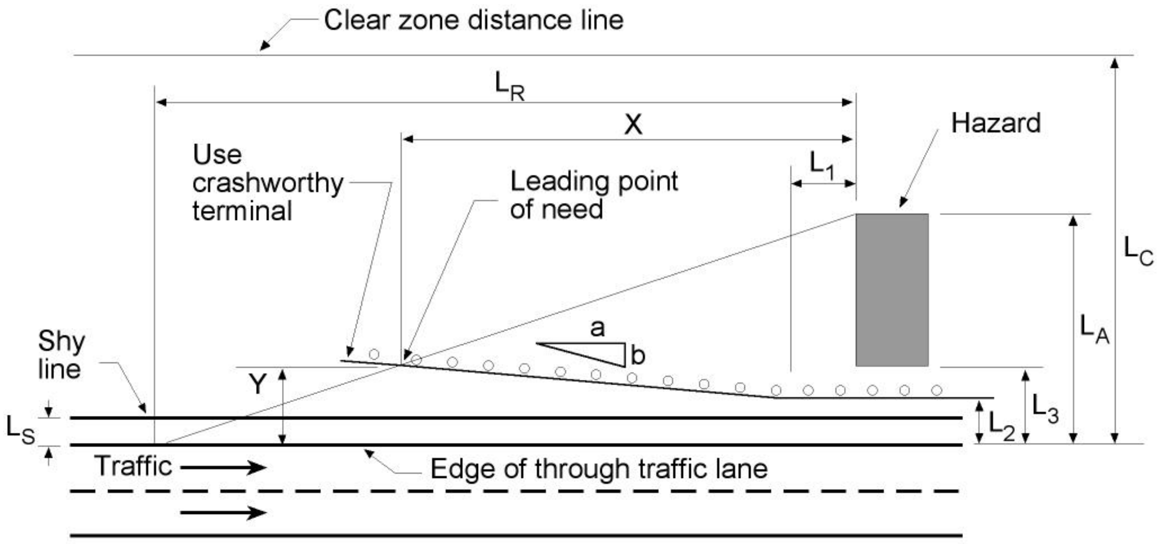
L_A = lateral extent of the area of concern

L_1 = tangent length of the road safety barrier upstream from the area of concern

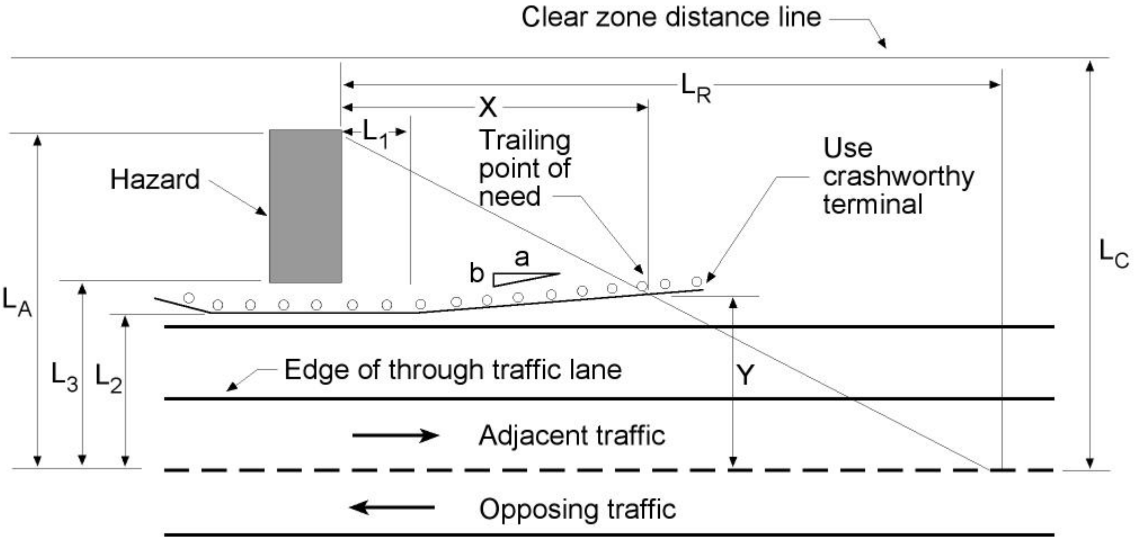
L_2 = road safety barrier's lateral distance from the edge of the running lane

Y = lateral distance from edge of traffic lane to point of need.

Figure I 1: Run-out length method of determining length of need



(a) Establishing leading point of need

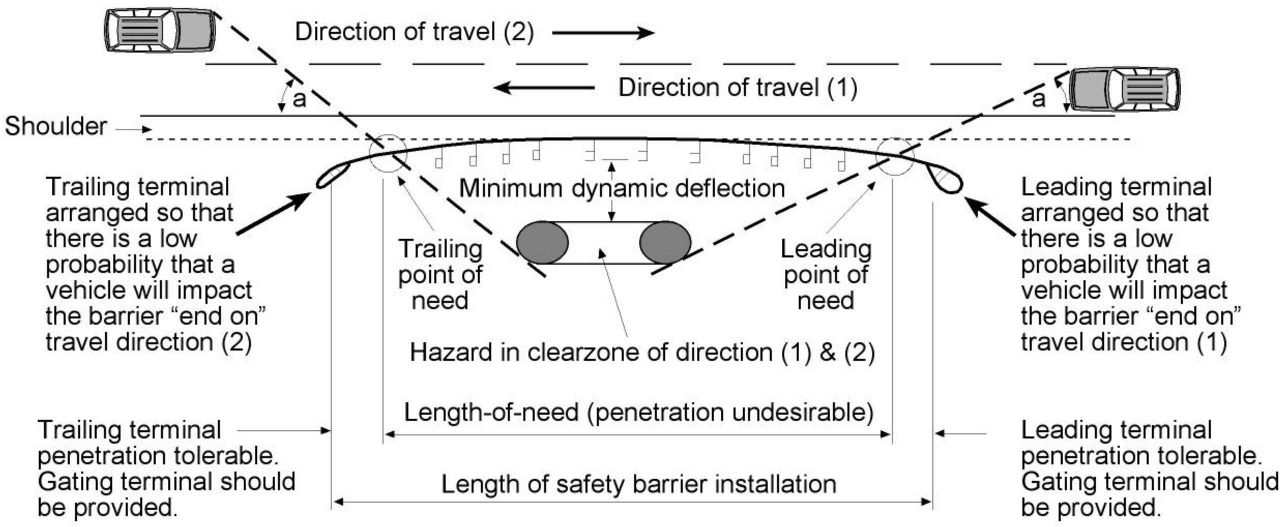


(b) Establishing trailing point of need

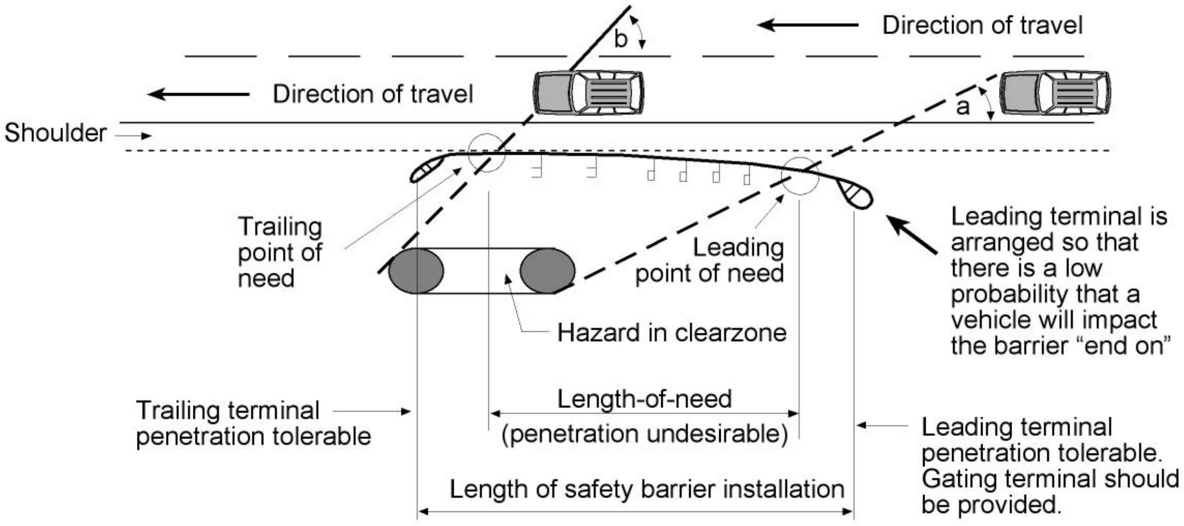
I.3 Angle of Departure Method

The angle of departure method is described in Section 6.3.19 and the relevant figure and table are reproduced here for convenience. The method is shown in Figure I 2 and appropriate angles of departure for use in calculations are shown in Table 6.10.

Figure I 2: Angle of departure method of determining length of need



(a) Two-lane two-way road



(b) Wide multi-lane carriageway or one-way carriageway

Source: Based on RTA (1996).

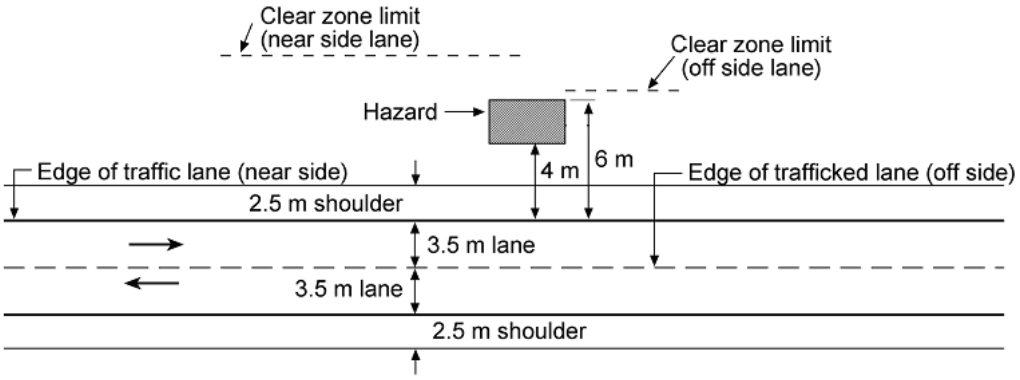
I.4 Worked Examples to Determine Road Safety Barrier Length of Need

The length of road safety barrier required in the following examples is computed using both the run-out length method and the angle of departure method. The examples assume a straight road alignment. While it is possible to perform similar computations for a curved alignment, the graphical method described in Section 6.3.19 is normally used.

I.4.1 Example 1

Determine the layout of a road safety barrier to shield a bridge pier (6 m long x 2 m wide) adjacent to a rural two-lane, two-way road as illustrated in Figure I 3. The AADT is greater than 600.

Figure I 3: Layout of Example 1



The road has the following characteristics:

AADT	14000
Commercial vehicles	2%
Design speed	100 km/h
Alignment	Essentially straight with flat gradient
Plan view	As per sketch; 2.5 m shoulder; pier 4 m from traffic lane; batter slope 6:1. Width of batter is 10 m

Need for a barrier and type of barrier

As a barrier is located closer to the road it might be impacted many more times than the hazard it is shielding and may not be warranted. If this is considered to be an issue then the designer should undertake a more comprehensive risk assessment to determine whether a barrier should be provided at all, or whether a flexible or two-stage barrier should be provided.

Table 4.1 in Section 4.2.2 indicates that the required clear zone is 10 m. Table E 8 shows that the severity of a W-beam (SI 2.7) is much less than a concrete pier (SI 6.0). Therefore, as the pier is located only 4 m from the traffic lane there is a high probability that it will be hit by errant vehicles and the consequences will be extremely severe. Consequently, a road safety barrier is required.

As the percentage of commercial vehicles is relatively low (2%) a road safety barrier that meets TL3 and caters for passenger cars should be sufficient.

As there is only 1.5 m from the rear edge of the shoulder to the face of the pier there is insufficient space to accommodate the relatively large deflections of a flexible road safety barrier (refer to Table 6.7 that provides indicative deflections for planning purposes, and bearing in mind that a WRSB will be located a small distance behind the edge of the shoulder).

Referring to Table 6.7 a W-beam (i.e. single rail with 2.0 m post spacing) may require a deflection distance of up to 1.4 m measured between the face of the barrier in its initial position and its final position after impact (refer to Figure 6.2). As a W-beam system has a system width of about 0.44 m its dynamic deflection cannot be accommodated within the 1.5 m. If a lesser dynamic deflection was assumed (e.g. 1.0 m from AS/NZS 3845 – 1999) a total distance of 1.44 m would be required and could be accommodated. However, this does not allow for a vehicle to roll should a high van impact the barrier (Figure 6.20 and Table 6.8) and adding a vehicle roll allowance of 0.8 m results in a total working width of 1.44 + 0.8 = 2.24 m. A similar process shows that a short section of Thrie-beam (deflection 0.6 m to 0.9 m) resulting in a minimum working width of 0.6 + 0.44 + < 0.8 = < 1.84 which is also > 1.50 m.

It is clear that a system stiffness greater than that of a standard W-beam or thrie-beam is required. Options that could be considered include the use of a rigid concrete barrier or a Thrie-beam that has reduced post spacing, or perhaps crash cushions.

Length of need using run-out length method

Consider first the lane nearest the hazard. The length of need for traffic in the lane nearest to the hazard on the approach to the hazard, as described in Section I.1, is given by:

$$X = [L_A + (b/a)(L_1) - L_2] / [(b/a) + (L_A/L_R)]$$

where

L_A	=	6.0 m	
b	=	1	Shy line is 2.4 m. Road safety barrier offset from traffic lane is 2.8 m i.e. 0.4 m outside the shy line (refer to Table 6.4). From Table 6.5 flare rate ratio b:a is 1:18
a	=	18	
L_1	=	4 m	Nominal, say one rail length
L_2	=	2.8 m	(2.5 + 0.3)
L_R	=	130 m	From Table 6.9

therefore

$$X = [L_A + (b/a)(L_1) - L_2] / [(b/a) + (L_A/L_R)] = [6.0 + 4/18 - 2.8] / [1/18 + 6.0/130] = 33.5 \text{ m.}$$

Note that this is the distance from the leading face of the pier to point of need for traffic approaching in the lane nearest the hazard, and that the length computed is for a flared end (i.e. Line A in Figure I 4).

The end of the concrete barrier should be shielded using a suitable leading terminal (i.e. crash cushion) which will increase the overall length (e.g. say 9.5 m).

Consider second the lane furthest from the hazard. The rear of the pier is offset from the opposing traffic lane by 9.5 m (6.0 + 3.5) and is therefore 0.5 m within the clear zone for the opposing direction. In this case:

L_A	=	9.5 m	
b	=	1	Refer to Table 6.4. Shy line for 100 km/h is 2.4 m from traffic lane and as the road safety barrier is 3.5 + 2.8 = 6.3 m from the opposing traffic it is well outside of the shy line distance. From Table 6.5 flare rate ratio b:a is 1:18
a	=	18	
L_1	=	4 m	Nominal, say one rail length
L_2	=	6.3 m	(2.8 + 3.5)
L_R	=	130 m	From Table 6.9.

Substituting these values in the formula:

$$X = [9.5 + 4/18 - 6.3] / [1/18 + 9.5/130] = 26.5 \text{ m.}$$

Note that this is the distance from the trailing face of the pier to point of need for traffic approaching in the lane furthest from the hazard, and that the length computed is for a flared end (i.e. Line A in Figure I 4). A suitable trailing terminal (i.e. crash cushion) which will increase the overall length (e.g. say by 9.5 m) should also be provided.

The overall length of road safety barrier required for traffic approaching from both directions therefore comprises the sum of the length required for the traffic in the lane adjacent to the hazard (leading), the length required for traffic in the opposing lane (trailing), plus the length of pier parallel to the road (i.e. 6 m).

Hence the overall length of need of the barrier = 33.5 + 26.5 + 6.0 = 66 m.

Note that the lengths of 33.5 m and 26.5 m will enable clear run-out areas measuring 18 m x 6 m behind the road safety barrier (refer to Figure 6.33) between the points of need and the hazard.

The overall length of barrier with two terminals may be about 85 m (depending on type of terminal).

The road safety barrier layout determined above is illustrated as the Line A installation (flared barrier) in Figure I 4. A Line B installation (parallel barrier) is also illustrated showing that a longer road safety barrier would be required with a tangential alignment (i.e. no flared ends). This can be computed for both the leading and trailing sides using the formula from Section 1.3, that is:

$$X = (L_A - L_2) / (L_A / L_R)$$

Therefore

X for leading point of need = $(6.0 - 2.8)/(6.0/130) = 53.3$ m

X for trailing point of need = $[(9.5 - (2.8 + 3.5)]/ (9.5/130) = 43.8$ m.

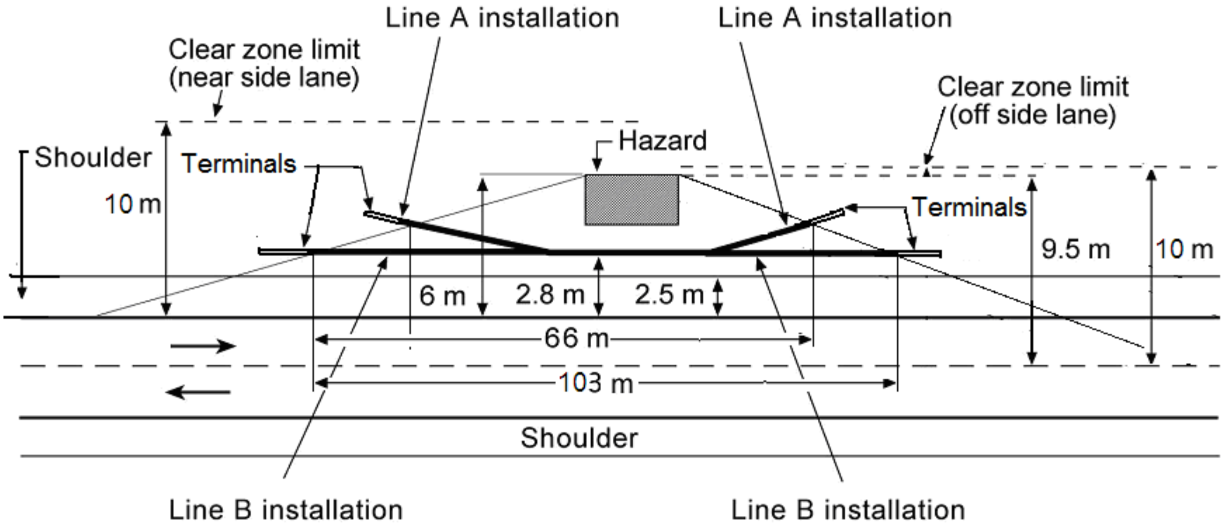
The overall length of need is given by the length on the leading side plus the length of hazard plus the length on the trailing side:

= 53.3 + 6 + 43.8 = 103.1 m.

Allowing for two terminals the overall length of barrier for Line B may be about 220 m.

In summary, a barrier that allows for flaring of both ends would be 66 m long between points of need and a barrier that is not flared at the ends would be 103 m long between points of need. The choice of the barrier alignment would often be governed by embankments and other geometric features.

Figure I 4: Example 1 options for road safety barrier layout



Length of need using angle of departure method

In the angle of departure method (Figure I 2) a vehicle travelling at 100 km/h is assumed to leave the road at a leading angle of 2.9° (Table 6.10). This equates to a rate of lateral shift of 20:1. This angle is applied from the edge of the travel lane to the rear extremity of the hazard for the adjacent traffic, and from the centre of the road to the clear zone for opposing traffic.

It is assumed that the road safety barrier in this example is located 2.8 m from the edge of the nearest travel lane.

Figure I 4 shows the general layout options for the barrier. For a straight alignment the lengths can be determined either graphically or by using simple algebra that relates to the geometry of triangles.

As the barrier is to be located 2.8 m from the edge of travel lane it is situated 6.0 – 2.8 = 3.2 m from the rear of the hazard at both the leading side and trailing side (i.e. for opposing traffic). The dimensions resulting from the angle of departure method are shown in Figure I 5.

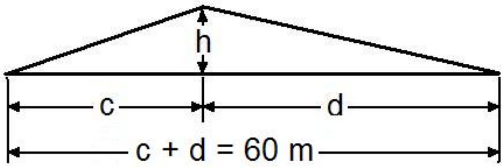
For Line B, the key factor is the rate of divergence (20:1) of the vehicle travel path from the edge of traffic lane, and as the barrier is parallel to the rear of the shoulder, the length of barrier between points of need is given by:

$L = 20 \times 3.2 + 6 + 20 \times 3.2 = 64 + 6 + 64 = 134$ m.

Assuming that the crashworthy end treatments (crash cushions) have a distance of 9.5 m from the leading end to the point of need, the overall length of barrier required along Line B is 134 + 2 x 9.5 = 153 m.

For Line A the length of barrier between the points of need can be determined either graphically or by applying geometry to the triangle enclosed by the vehicle trajectory, Line B and Line A (Figure I 5).

For the leading length of need the base of the triangle is 64 – 4 = 60 m long. As the vehicle trajectory is 1 in 20 and the flare of the barrier is 1 in 18 the length of the side of the triangle along the road safety barrier can be determined from equations for the height of the triangle as follows:



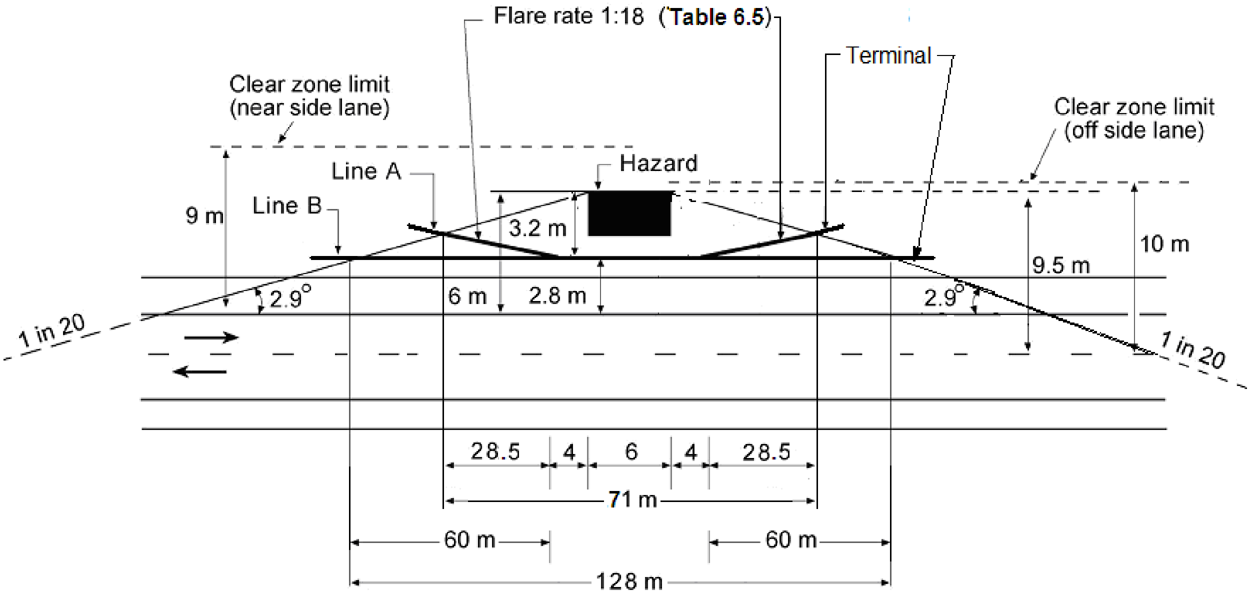
h = c/20 = d/18 and as c = 60 - d the equation becomes:

(60 - d)/20 = d/18 which can be solved to determine that d = 28.5 m.

The length of the barrier can then be solved but at such a small slope will approximate d. The length of barrier required from the leading point of need to the hazard is therefore 28.5 m plus the nominal 4 m long section of straight barrier (i.e. 32.5 m). The same length will apply to the trailing side of the hazard (Figure I 5).

Therefore, the length of barrier between points of need = 32.5 x 2 + 6 = 71 m and the overall length of road (incl. terminals) could be 71 + 2 x 9.5 = 90 m (depending on type of terminal).

Figure I 5: Example 1 using angle of departure method

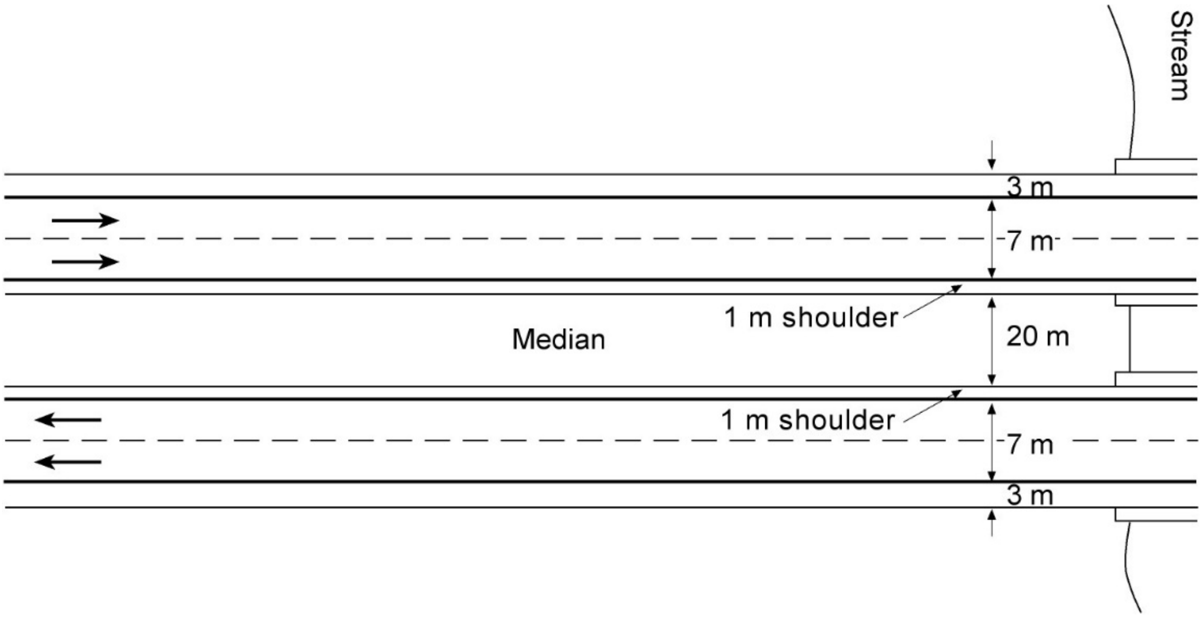


In summary using the angle of departure method, a barrier that allows for flaring of both ends would be 71 m long between points of need and a barrier that is not flared at the ends would be 134 m long between points if need. Again, the choice of the barrier alignment would often be governed by embankments and other geometric features.

I.4.2 Example 2

Determine the layout of a barrier to shield the end of a bridge barrier on a divided rural highway as illustrated in Figure I 6.

Figure I 6: Layout of Example 2



The road has the following characteristics:

AADT	15000 vpd
Commercial vehicles	15%
Design speed	110 km/h
Alignment	Essentially straight with flat gradient
Plan view:	As per sketch; twin bridges with spill through abutments and descent to stream; 3.0 m shoulder on left, 1 m shoulder on right; bridge barrier end immediately behind shoulder; batter slope left side 4:1 and median 6:1. The batter is 3.5 m high and 14 m wide with a clear run-out area greater than 3 m in width beyond the toe

Consideration of the type of treatment

As the batter is traversable it requires a clear run-out area at least 3 m wide beyond the toe. This should enable errant vehicles to traverse it at an angle, travel longitudinally at the base and come to rest. The task is therefore to shield vehicles from leaving the road close to the end posts and either crashing into the end posts or plummeting into the stream.

It is considered impracticable to flatten the embankment behind the line of road safety barrier rail for a distance wide enough to accommodate the deflection of flexible barrier. The nature of the stream and the type of commercial vehicles may be a consideration in determining the type of semi-rigid road safety barrier to be adopted.

Length of need using run-out method

Consider firstly the left side of the carriageway. For an AADT of 15000 vpd, a design speed of 110 km/h and a 4:1 batter, Table 4.1 indicates that the required clear zone distance is 14 m on the left side of the road. In view of the embankment height and slope on the left side it is impracticable to flatten the batter so that a preferred flared barrier alignment is able to be provided. Consequently, a tangent barrier system and associated terminal treatment (i.e. one aligned along the rear of shoulder and not flared) is the appropriate installation.

The run-out method is applied to a point in the roadside a lateral distance from the end post equal to the clear zone (i.e. 14.0 m). As there is no flare and the rail is coincident with the rear of the shoulder, the length (X) from the end of the bridge barrier to the point of need is computed by applying similar triangles as given in the formula:

$X = (L_A\text{-}L2)/(L_A/L_R)$

where

L_A = 14.0 m

L_2 = 3.0 m

L_R = 145 m From Table 6.9

therefore

$X = (14.0 – 3.0)/(14.0/145) = 113.9$ m (distance from leading face of pier to point of need).

A crashworthy transition must be provided to the bridge end post (refer to AS/NZS 3845:1999, Figure F 9) and its length will be included in the 113.9 m. A crashworthy leading end treatment (gating terminal) must also be provided. The point of need is assumed to be about 4 m from the leading end of the barrier (varies depending on the product used) and consequently the overall length of barrier required is 113.9 m + 4 m = 117.9 m.

Consider secondly the median at the bridge. As the slope on the median is 6:1 the clear zone width in the median is 10.5 m (Table 4.1).

A flared barrier alignment could be used as the 6:1 median slope can be flattened to 10:1 in the area between the carriageway and the barrier. The median slope behind the barrier may have to be steepened to satisfy drainage requirements.

Referring to Table 6.4 the shy line for the right hand side on a 110 km/h road is 2.0 m from the edge of the traffic lane. Consequently, the barrier will commence within the shy line and should flare at a rate of 1 in 30 (Table 6.5) and the length (X) from the end of the bridge barrier to the point of need is computed by:

$X = [L_A + (b/a)(L_1) – L_2] / [(b/a) + (L_A/L_R)]$

where

L_A = 10.5 m

b = 1 Table 6.4, shy line is 2.0 m from traffic lane and road safety barrier is 1 m within the shy line. From Table 6.5 flare rate ratio b:a is 1:30

a = 30

L1 = 10.0 m Length of transition from AS/NZS 3845 – 1999, Figure F 9.

L2 = 1.0 m Width of shoulder

LR = 145 m From Table 6.9

Therefore

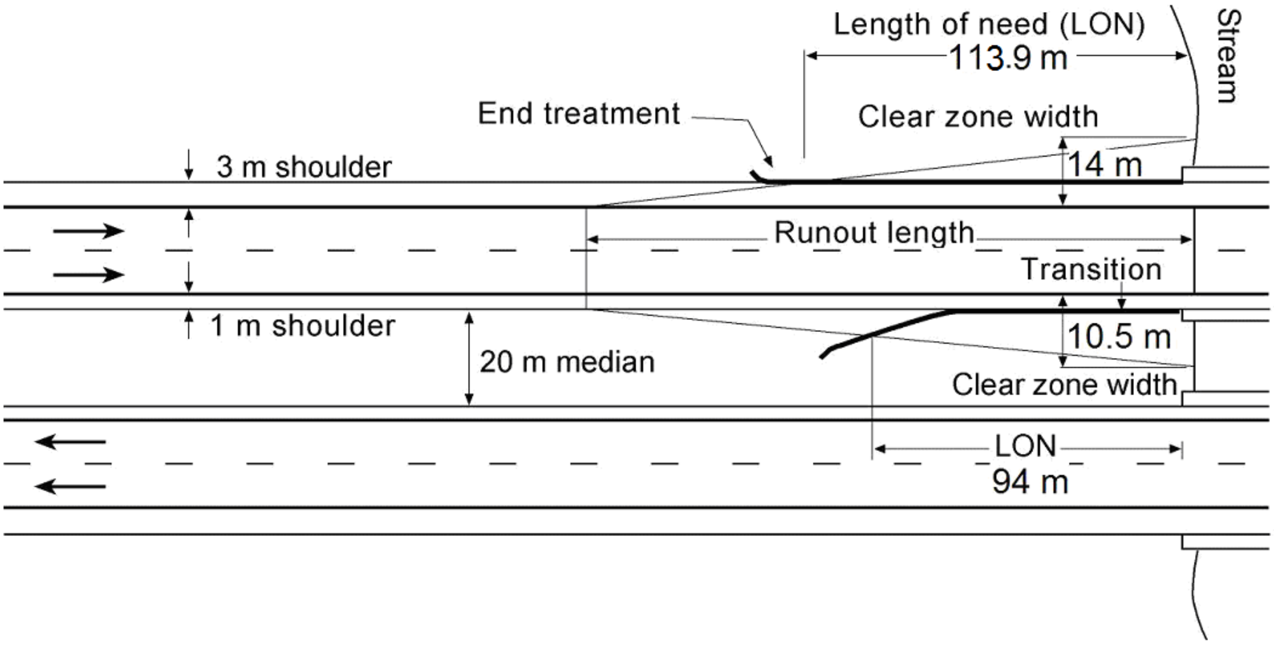
$X = [10.5 + (1/30)(10.0) – 1.0] / [1/30 +10.5/145] = 93.65$ m (say 94 m).

A MELT terminal (non-proprietary product) can be accommodated in the median to provide a gating terminal with a traversable area 18 m long by 6 m wide behind the barrier, measured from the point of need. The point of need for the MELT is two post spacings from the leading end. Hence the overall length of road safety barrier is 94 + 4 = 98 m.

Adoption of a higher flare angle (1 in 15 when the barrier is outside the shy line) would reduce the required barrier length by about 20 m. However, increasing the flare angle has operational disadvantages in that the angle of impact and severity of crashes increase and there is an increased likelihood that a vehicle will be redirected back into or across the carriageway following an impact.

The barrier arrangements determined above are illustrated in Figure I 7.

Figure I 7: Example 2 option for road safety barrier layout: run-out length method



Length of need using the angle of departure method

In the angle of departure method (Figure I 2) a vehicle travelling at 100 to 110 km/h is assumed to leave the road at a leading angle of 2.9° (Table 6.10). This equates to a rate of lateral shift of 1 in 20. This angle is applied from the edge of the travel lane to the rear extremity of the hazard for the adjacent traffic, and from the centre of the road to the clear zone for opposing traffic. Lengths relating to the application of the angle of departure method are shown in Figure I 8.

Consider the left side of the carriageway. Because of the batter characteristics a tangent road safety barrier (Line B type) is necessary. Assuming that the road safety barrier is coincident with the back of the shoulder, it can be seen that:

Length of need = (14.0 – 3.0) x 20 = 220 m

Length of road safety barrier = 220 + 4 (terminal) = 224 m.

Consider the median side of the carriageway. Because the median shoulder is 1.0 m wide the road safety barrier is within the shy line and a flare rate of 1 in 30 applies (refer to Table 6.5).

The distance between points of need can be determined either graphically or by applying geometry to the triangle enclosed by the vehicle trajectory, the back of the shoulder and the barrier (refer to Figure I 8).

The distance from the end of the structure to the point where the vehicle trajectory crosses the rear of the shoulder is:

(10.5 – 1.0) x 20 = 9.5 x 20 = 190 m.

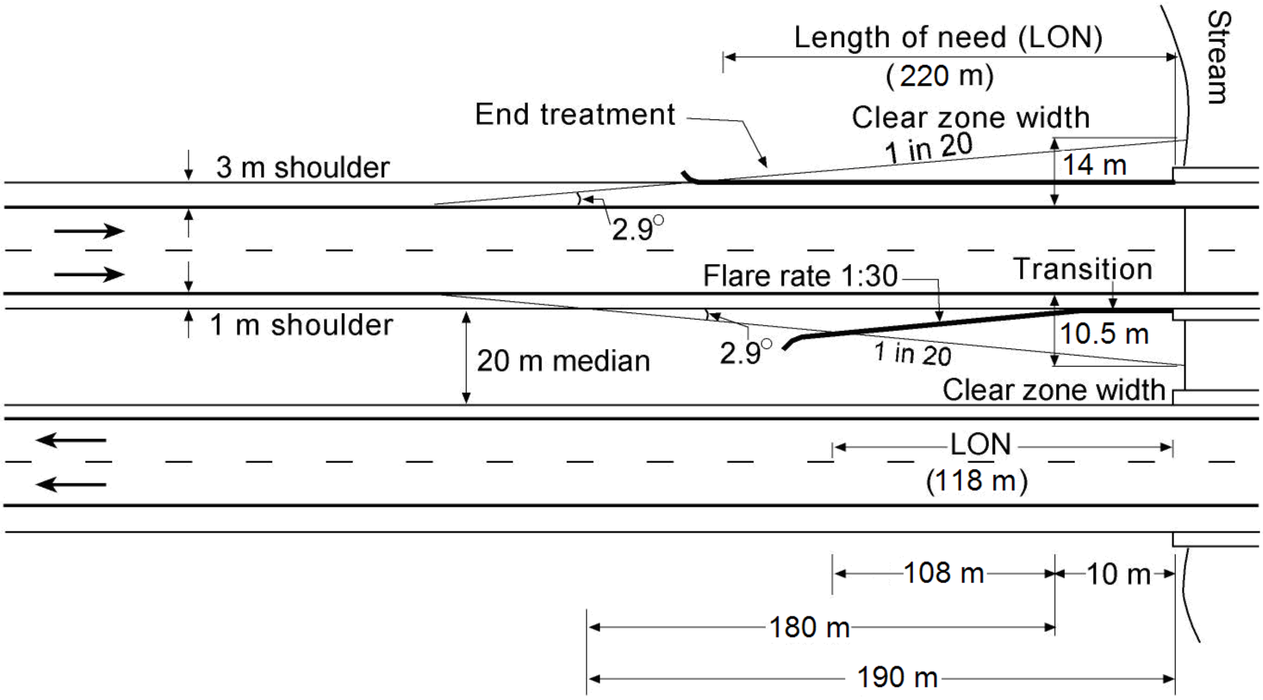
Assuming that the transition between the road barrier and the bridge barrier is 10 m, the length (along the shoulder) of the base of the triangle is 190 m minus the transition length = 180 m.

The vehicle trajectory rate of lateral shift and the barrier flare rate can be used to compute the length of barrier along the side of the triangle:

30/(30 + 20) x 180 = 108 m.

Therefore the length of need of the barrier is = 108 m + transition length = 118 m and the overall length of road safety barrier = 108 + 4 (MELT) = 122 m (adopt 31 rails x 4 m = 124 m).

Figure I 8: Example 2 option for road safety barrier layout – angle of departure method



Appendix J Types of Safety Barrier Terminals

J.1 General

Road safety barrier terminals may be public domain or proprietary products. At sites that are unsuitable for a public domain terminal treatment (e.g. MELT refer to Section J.1.1) it will often be necessary to provide a proprietary terminal treatment. However, in suitable situations it may be appropriate to terminate a road safety barrier in a cutting face or a back slope. Such public domain, buried terminal treatments can be effective and may be used provided that they are designed and crash tested (including the anchor) to meet the requirements of the appropriate test level. This type of treatment may be appropriate where:

- A road passes through a series of cut to fill lines, the cuttings are steep (e.g. say 0.5:1 or steeper), smooth and able to redirect vehicles, and road safety barrier is required between the cuttings. This may require the use of a suitably designed end treatment/transition to anchor the road safety barrier (e.g. perhaps in the shape of a concrete road safety barrier), that does not require significant disturbance of the cutting face.
- However, in deciding to adopt this technique designers should be confident that the batter approaching the barrier system will redirect an errant vehicle and not result in the vehicle travelling up the batter and behind the barrier.
- A suitably designed flat-bottomed drain or V drain exists at a site and it is desirable that the barrier passes through the drain and is buried in a 4:1 back slope (refer to the *Guide to Road Design - Part 3: Geometric Design* (Austroads 2009b) for suitable drain profiles). These buried terminals have been successfully tested at test level TL3; refer to USA Federal Highway Administration website, FHWA approval letter CC-53 (FHWA 1998) and CC-53A (FHWA 2001). Key design considerations include:
- the height of the W-beam should remain constant relative to the roadway grade until the road safety barrier crosses the flow line of the drain
- a flare rate, appropriate until the road safety barrier reaches the flow line
- adding a rubbing rail
- using an appropriate anchor (concrete block or steel post) that is capable of developing the full tensile strength of the W-beam rail.

J.1.1 Specific Gating End Treatments

Public domain treatments

Gating end treatments that are acceptable under AS/NZS 3845 – 1999, and are available in Australia include non-proprietary treatments such as the:

- modified eccentric loader terminal – MELT
- leading slotted break away cable terminal – SBCT.

AS/NZS 3845 – 1999 gives further details on public domain systems.

When these terminals are installed on curves the offset to the terminal should not be measured from a tangent to the curve as this will lead to an exaggerated flare rate and high impact angles by errant vehicles. Consequently, the offsets should be measured from the curve.

Modified eccentric loader terminal – MELT

This end treatment is included in AS/NZS 3845 – 1999. The MELT is considered to offer improved safety, particularly for the smaller Australian passenger car. It has therefore superseded the break away cable terminal (BCT) which is no longer used. It is essential that the MELT should only be used with the standard 1.25 m offset of the parabolic flare as any offset flare smaller than this may be hazardous for occupants of smaller vehicles. This may result because sufficient kinetic energy may not be developed in collisions by smaller vehicles to ensure that the terminal's rail collapses under an eccentric load. The general arrangement of the MELT and the run-out area is shown in Figure J 1.

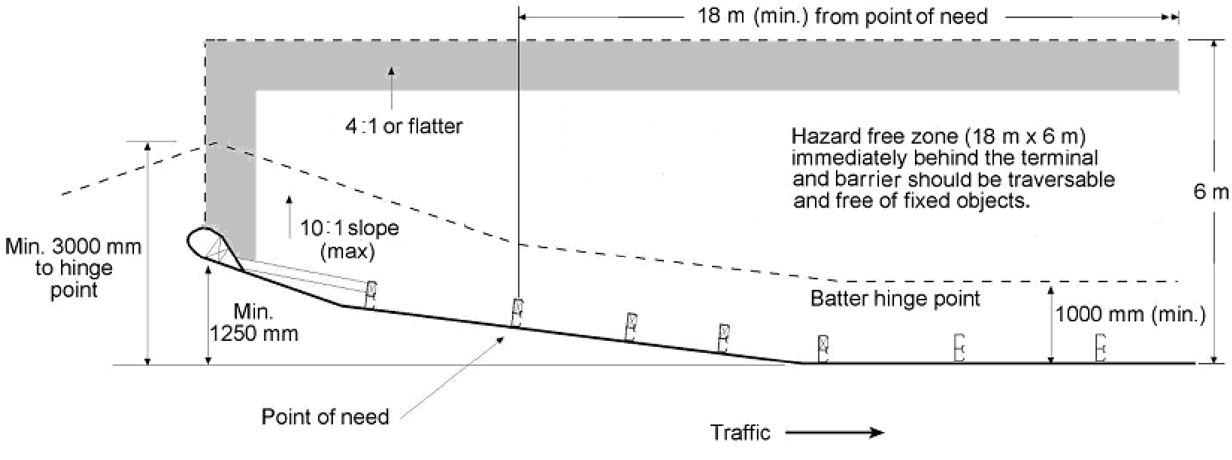
The original MELT, when tested at 100 km/h to National Cooperative Highway Research Program (NCHRP) Report 350 test level 3 (TL-3), was considered unsatisfactory because the pickup truck, after breaking through the terminal and travelling behind the rail, eventually struck the support posts from behind, spun sideways and overturned. However, a slightly modified version of the MELT was subsequently tested and certified as an NCHRP Report 350 TL-2 design (FHWA acceptance letter HAS-10/CC-84) (FHWA1984).

As with all gating, non-energy absorbing W-beam terminals, the MELT does not absorb significant crash energy when struck end-on and therefore should be used only in locations where, for shallow-angle (i.e. essentially end-on) impacts, a reasonable recovery area exists behind and essentially parallel to the barrier.

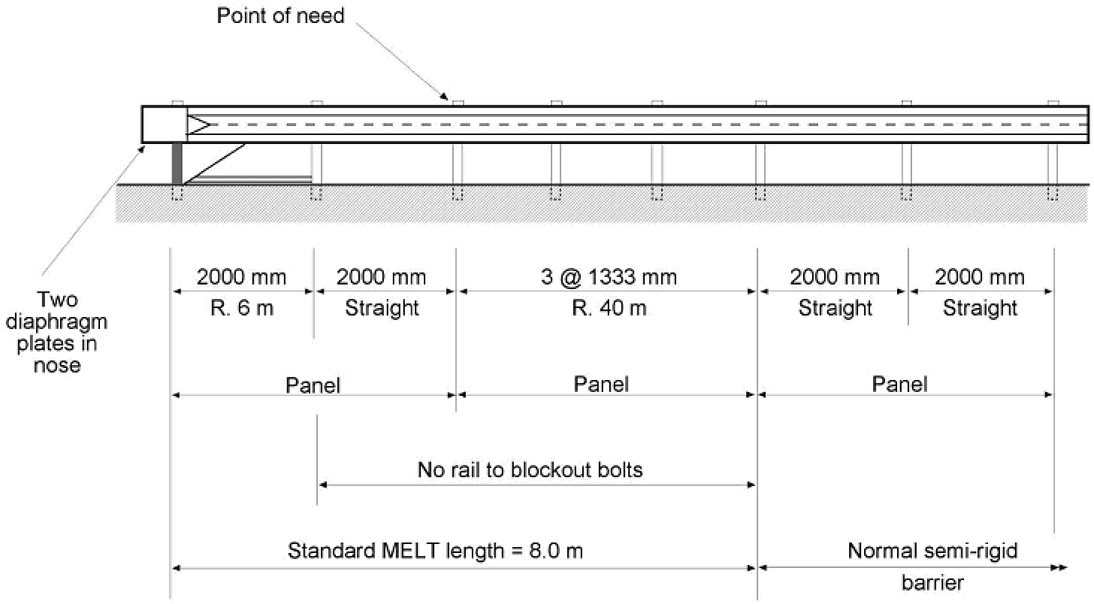
Designers are referred to AS/NZS 3845 – 1999 for details of the MELT system which is acceptable for use under the standard.

The design of the break away cable terminal (BCT) had been tested successfully with vehicles having a mass of 1020 kg and 2000 kg. However, testing with vehicles of 820 kg mass has shown that the BCT was too stiff to buckle readily under reduced energy crashes from this class of vehicle. The vehicles of smaller mass did not develop sufficient kinetic energy to activate the pivoting mechanism and testing showed that this class of vehicle was more susceptible to rotational forces than the larger mass vehicles. In some situations the BCT also resulted in the spearing of vehicles that impacted the system end-on. The BCT is therefore no longer recommended for use where there is a significant risk of vehicles colliding head-on with the BCT at its end.

Figure J 1: General arrangement of the modified eccentric loader terminal (MELT)



Plan



Elevation

Slotted break away cable terminal – SBCT

The SBCT is also included in AS/NZS 3845 – 1999 and is an alternative to the MELT. It has not passed NCHRP 350 (1993) testing but it is accepted for use under AS/NZS 3845 – 1999. The first five posts of the road safety barrier are weakened timber posts (4 x 20 mm holes 100 mm above ground level) whilst the end section of the road safety barrier rail is slotted in the first two spans and curved on a 40 m radius away from traffic. This weakening of posts and rail enables the terminal to ‘gate’ on impact so that vehicles, including light cars, can pass through the end treatment with an acceptable level of severity.

No blockout is provided on the first post and the blockout and backing plate are omitted on the first intermediate post. The SBCT is similar to the MELT and is illustrated in AS/NZS 3845 – 1999. It also requires a traversable run-out area extending a minimum of 18 m beyond the point of need and at least 6 m wide from the rear of the barrier.

As the SBCT is not used in some jurisdictions designers should consult the relevant road authority policy and guidelines.

Proprietary products

Most crash attenuators including those that gate (refer to Figure 6.34) are generally patented proprietary products and the manufacturer's specifications and representative should be consulted to establish the availability of new and improved products that have passed the required testing procedures. In addition, the designer should consult with the relevant road authority to determine specific acceptance criteria relating to new and improved products. Up-to-date information, including in-service reports about crash attenuator features should also be used for the selection/design procedure, it being recognised that specific and highly controlled crash tests are not always adequate indicators of how crash attenuators will perform in different situations.

The number and complexity of factors that enter the selection process for crash attenuators preclude the development of a simple selection procedure. Each operational system has its own unique physical and functional characteristics. In some cases, one crash attenuator will stand out as the most appropriate, but in most cases two or more types will provide satisfactory protection to an errant motorist, and the designer must choose between them (AASHTO 2006). The designer must therefore refer to the manufacturer's specifications and literature to develop a good understanding of the installation requirements of each device and its behaviour under impact, so that the most appropriate product can be selected for any given situation. The Federal Highway Administration (FHWA) web site and approval letters should also be consulted.

Many attenuators provide a gating function and use various principles and mechanisms through which a safe end treatment is achieved. In all cases site preparation and the installation of the device must meet the manufacturer's specifications. In particular, the point of need may vary between products. Products that provide a gating terminal may use the following methods of operation.

Displacement of sand

The containers are held together (e.g. by cables or other devices) and upon impact the deceleration of the vehicle is controlled through displacement of the sand contained in deformable containers. The energy of the vehicle impact is transmitted to the weights of sand in the barrels, thus dissipating the collision energy based on the principle of conservation of momentum. It is essential that the sand used meets specific material grading requirements.

The force of impact is not transmitted through the barrels so backup structures or walls are not required for these systems. The systems can be used as either a crash attenuator placed directly in front of the hazard, or as a road safety barrier end treatment. However, they will not redirect some side crashes, particularly those occurring toward the rear of the installation. Damaged modules must be replaced after each impact.

These systems can be used to protect hazards of any width and are particularly suited to gore areas. They can be used on the left side of the road or in medians. The site must be well compacted and be able to accommodate a concrete or asphalt foundation pad and the transverse slope should not exceed 20:1.

Designers should note that the water content (typically 3%) in the sand might freeze if systems are installed in mountainous regions and cold weather continues for several days. In this situation, the attenuators will not work as designed. Mixing rock salt (5 to 25% by volume) with the sand will help reduce the possibility of errant vehicles hitting barrels of frozen sand.

Collapsible steel beams and posts

These systems generally involve a structure of W-beams, posts and cable anchorages. Collision energy is dissipated by the breaking away of the posts and shearing as W-beams telescope into each other.

If the first post is damaged in any way, a system may lose its re-directive characteristics. Some systems may also include containers filled with sand, liquid or other crushable material that contribute to the attenuation qualities of the end treatment.

An entire system or some of its components may not be able to be salvaged and used again after a major crash, and nuisance crashes may result in a system not operating as it should.

Deformation of a steel beam

These end treatments employ a steel impact-head mounted at the leading end of the system. On impact, the head is pushed along the W-beam, causing the rail to deform, curl around or shred, thus dissipating the collision energy.

These systems require sufficient width in the verge to accommodate the discarded rail sections and it is important to establish whether the rail is extruded onto the traffic side of the system or to the back of the system. An obstacle-free area for a distance of 18 m beyond the point of need of the barrier system (parallel to the rails) and at least 6 m behind the rails is generally necessary. Systems may be designed to suit straight or flared road safety barrier alignments.

J.1.2 Non-gating End Treatments

Most non-gating end treatments are crash attenuators that do not allow a colliding vehicle to pass behind the terminal (refer to Figure 6.34). On colliding with the end of the terminal, the vehicle will be redirected away from the road safety barrier or be arrested by the barrier.

Because non-gating end treatments do not require a clear, level area behind the barrier, their application is suited to:

- median barrier ends where it is important to prevent colliding vehicles from encroaching onto the opposite carriageway
- situations where a run-out area is not available, thus precluding the use of a gating terminal.

Non-gating end terminals are appropriate for shielding:

- road safety barrier ends, including those in medians
- exit ramp gore areas
- fixed objects located within the clear zone
- bridge rail ends
- bridge piers.

Non-gating terminals employ similar principles to gating terminals whereby crushable containers or cylinders, collapsible structures and other mechanical devices (e.g. guide cables) may be employed. Some systems may dissipate the energy of the impact through a braking mechanism and the nesting of barrier rails. Others may employ rubber components or crushable materials that are capable of being re-used after impact.

All impact attenuation systems available at present are patented products and must be installed in accordance with the manufacturer's specification.

Public domain end treatments

Where there is a need to install parallel semi-rigid road safety barriers, for example to shield a bridge pier in a median, the public domain ‘bull-nose’ treatment shown in Figure J 2 may be suitable. The bull-nose is constructed of a circular section of slotted thrie-beam supported by break away posts. The end treatment is suitable for use with W-beam or thrie-beam barriers through the use of appropriate transition sections.

When a vehicle crashes into this bull-nose the posts in the nose break away and the rail deforms inward, arresting the vehicle in the process. For the bull-nose to deform as intended under impact, the rail in the nose section should not be bolted to the posts, and the bolt heads in the first section of rail at the sides should not be provided with washers. A similar arrangement with splayed sides can be used to shield objects in gore areas of off-ramps. Where necessary, a sign support may be installed behind the bull-nose provided that it has a break away support.

The area within the bull-nose barrier system for a distance of 19.0 m beyond the nose must be free of hazards (refer to Diagram A in Figure J 2). This requirement is based on a 100 km/h test. It should also be noted that the original system was crash tested with timber break away posts.

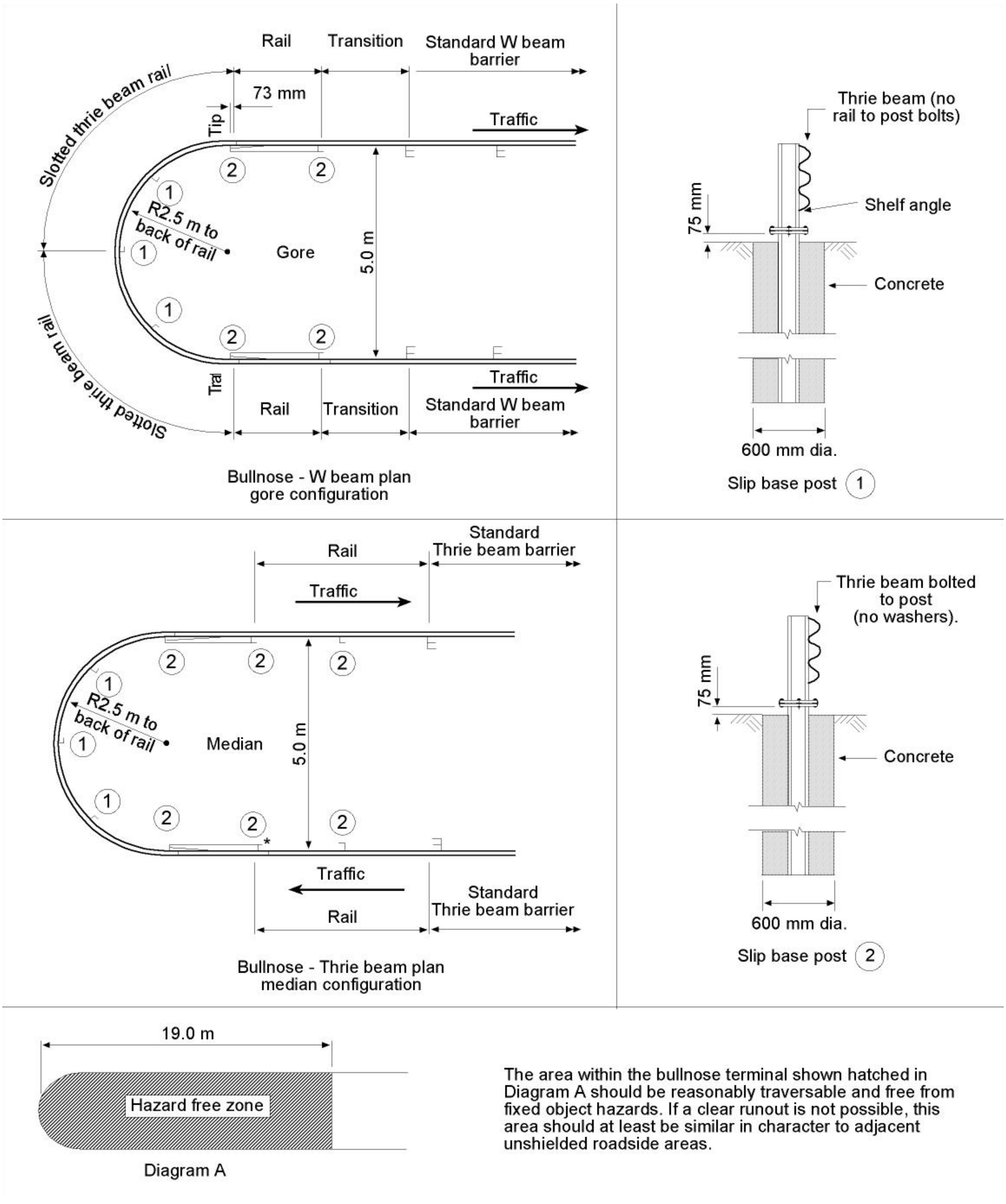
Proprietary products

Non-gating crash attenuators are also available for use in situations where it is not desirable to allow vehicles to pass through the nose section of the attenuator. They are generally patented and the manufacturer’s specifications and representative should be consulted to establish the availability of new and improved products that have passed the required testing procedures. In addition, the designer should consult with the relevant road authority to determine specific acceptance criteria relating to new and improved products.

As is the case for gating proprietary products designers must refer to the manufacturer’s specifications and literature for non-gating proprietary products to develop a good understanding of the installation requirements of each device and its behaviour under impact. This should ensure that the most appropriate product and design is used for any given situation.

The point of need for non-gating attenuators is at the nose.

Figure J 2: An example of a non-proprietary bull-nose attenuator



The area within the bullnose terminal shown hatched in Diagram A should be reasonably traversable and free from fixed object hazards. If a clear runout is not possible, this area should at least be similar in character to adjacent unshielded roadside areas.

Note:

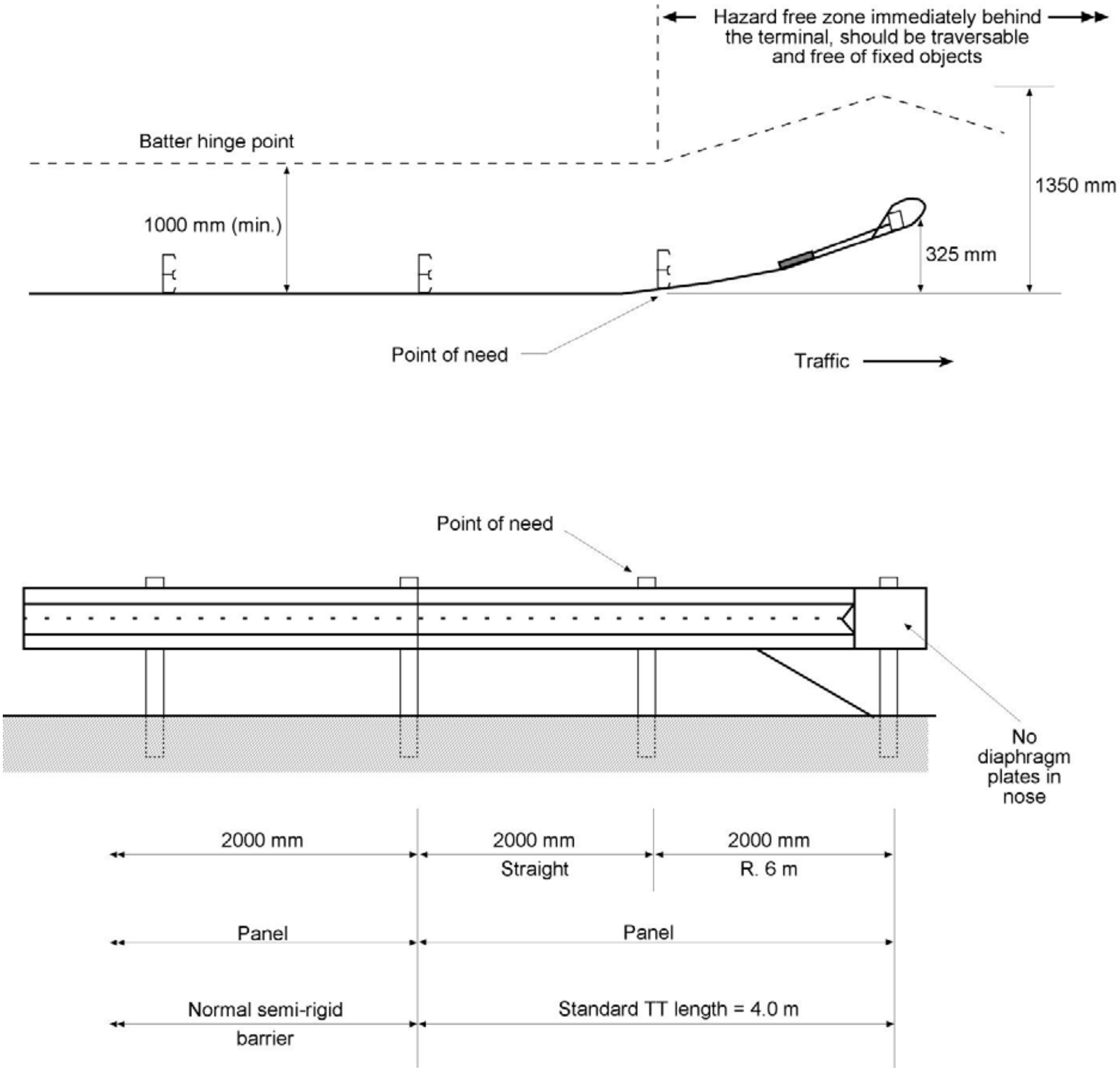
Original system was crash tested with timber break away posts.

Source: Based on Queensland Department of Main Roads Standard Drawing No. 1488.

J.1.3 Trailing Terminal

This terminal is shown in Figure J 3 and incorporates a cable anchorage. Its main function is to provide a cable anchorage at the trailing end of the system. Whilst this terminal will gate, it is not a crashworthy terminal and should only be used on installations (e.g. on a wide duplicated road) where there is no possibility of an errant vehicle from the opposing traffic flow striking the trailing end of road safety barrier end on. Therefore the trailing terminal should not be used within the clear zone for traffic from the opposing direction. Where the trailing end of an installation is located within the clear zone for opposing traffic a MELT or other appropriate crashworthy terminal should be used.

Figure J 3: Trailing terminal



Appendix K Transitions Between Barrier Types

K.1 General

Transitions are used to provide a safe interface whenever it is necessary to change from one type of barrier to another. A satisfactory interface may be achieved by:

- Providing a structurally designed and tested physical connection between the systems. The connections are facilitated through transition sections of barrier that are designed to provide gradually increasing lateral stiffness and hence continuity of protection for vehicles that impact the barrier in the vicinity of the interface. Transitions can be used only between semi-rigid systems (i.e. steel to steel) or between semi-rigid and rigid systems (i.e. steel to concrete).
- Overlapping the barriers by commencing the more rigid system behind the less rigid system.

The purpose of a transition section is to produce a gradual increase in stiffening between the barrier systems so that vehicular pocketing, snagging or penetrations are prevented at any position along the transition. The overlapping of the barriers achieves a similar outcome by providing adequate lateral separation between them.

In practice transitions are achieved by:

- increasing the rigidity of a W-beam system by
- decreasing the post spacing
- nesting one rail behind another
- using another steel section behind the W-beam
- using a heavier rail for the transition (e.g. thrie-beam).

Overlapping different types of barrier is only possible where adequate space is available to accommodate deflections. This may be used for any systems but is the only way of achieving a transition from wire rope barrier to a more rigid barrier.

Specially designed barrier sections or connections are used for situations where W-beam is to be connected to thrie-beam, or where either of these semi-rigid barriers are to be connected to a rigid barrier (refer to AS/NZS 3845 – 1999). The latter situation typically arises on the approach to bridges that have rigid barriers, but may also occur at other locations.

The Federal Highway Administration website provides details of crash tested transitions (http://safety.fhwa.dot.gov/fourthlevel/hardware/listing.cfm?code=long).

K.2 Design Criteria – Physically Connected Barriers

Several criteria are important when designing a transition section or connection (AASHTO 2006). Although AASHTO provides this guidance in relation to bridge approaches, the following principles apply where any semi-rigid barrier system is connected to a rigid barrier.

- The connection point of the two systems must be as strong as the approach barrier to ensure that the connection will not fail on impact by pulling out. The use of a cast-in-place anchor or through-bolt connection is recommended.
- The transition must be designed to minimise the likelihood of snagging an errant vehicle, including one from the opposing lane on a two-way facility.
- When providing a transition section to a bridge railing end it is highly desirable to taper the bridge railing end behind the approach transition to prevent pocketing on vehicle impact.

- The transition should be long enough to ensure that changes in deflection do not occur over a short distance. The change in stiffness from the less rigid barrier to the more rigid barrier, over the transition length, should increase with a high degree of continuity. This may be achieved by reducing the post spacing, strengthening the rail element or a combination of these techniques.
- As with longitudinal barriers, kerb and slope features must be addressed. The slope between the edge of the road and the barrier should not be steeper than 10:1.
- Drainage features such as kerbs, kerb inlets, raised inlets or open drains should not be constructed in front of barriers or a transition area, as they may initiate vehicle instability and adversely affect the crashworthiness of the barrier or transition.

K.3 Typical Interfaces between Barrier Types

K.3.1 General

AS/NZS 3845 – 1999 provides detailed illustrations of transitions between semi-rigid and rigid barriers. These transitions have been tested or are deemed to be acceptable with respect to NCHRP 350 (1993). The transitions are achieved through stiffening of the steel safety barrier by the use of special sections and connectors, reduced post spacing and nesting (i.e. two sections of rail, one inside the other) of the beams.

Wire rope safety barriers (WRSB) are not designed to be connected to semi-rigid or rigid safety barriers or bridge ends. However, WRSB may be transitioned to more rigid barriers provided that the WRSB overlaps the more rigid barrier by an adequate longitudinal distance and the lateral separation is sufficient to accommodate the maximum likely deflection of the WRSB. Such arrangements should enable the two systems to work independently while providing continuous shielding of hazards.

The WRSB manufacturer should be consulted with regard to any proposed design transitions between WRSB and semi-rigid or rigid barriers to seek assurance that they have either been tested or have been otherwise demonstrated to be acceptable.

Guidance on various transitions is provided in the following sections.

K.4 W-beam to Thrie-beam

The transition is achieved through the use of a product that bolts to the W-beam at one end and to the thrie-beam at the other end. This transition is 2 m between post centres and is illustrated in Figures F5 and F15 of Appendix F of AS 3845 – 1999.

K.5 W-beam to Concrete

W-beams are connected to a concrete barrier either through the use of a thrie-beam transition (Figure F5 in AS 3845 – 1999) or by connecting the W-beam directly to the concrete using an acceptable direct transition (Figure F9 in AS 3845 – 1999). Both treatments provide a structurally sound connection and a smooth and stiffened transition to prevent snagging and pocketing of impacting vehicles.

The Thrie-beam transition involves:

- the use of a prefabricated product to connect the W-beam to the thrie-beam (Figure F15 of AS 3845 – 1999)
- the post spacing being reduced from the standard spacing (2 m) to 1 m for five spaces and then to 500 mm for the two spaces prior to the concrete barrier
- nesting of the thrie-beam over the last 4 m prior to the concrete barrier

- the use of a structure connector to bolt the thrie-beam into a recess in the concrete barrier (Figure F27 of AS 3845 – 1999).

The W-beam transition (directly to concrete barrier) involves the:

- W-beam being recessed into the concrete barrier to provide a flush barrier face at the connection
- transition being strengthened by the post spacing being reduced progressively from the standard spacing (2 m) to 1 m and then 500 mm over the last 10 m of the beam
- transition being further strengthened by nesting of the W-beam over the last 5 m
- concrete barrier being flared away from the W-beam, the latter being stiffened by circular hollow sections bearing on the face of the concrete at the rear of the beam.

K.6 Thrie-beam to Concrete

The transition between thrie-beam barrier and concrete barrier is achieved through the use of a structure connector, as shown in Figure F27 of AS 3845 – 1999, which enables the Thrie-beam to be bolted into a recess in the concrete barrier. Details of the transition are shown in Figure F6 of AS 3845 – 1999. The Thrie-beam is stiffened in the manner described in K.5 above.

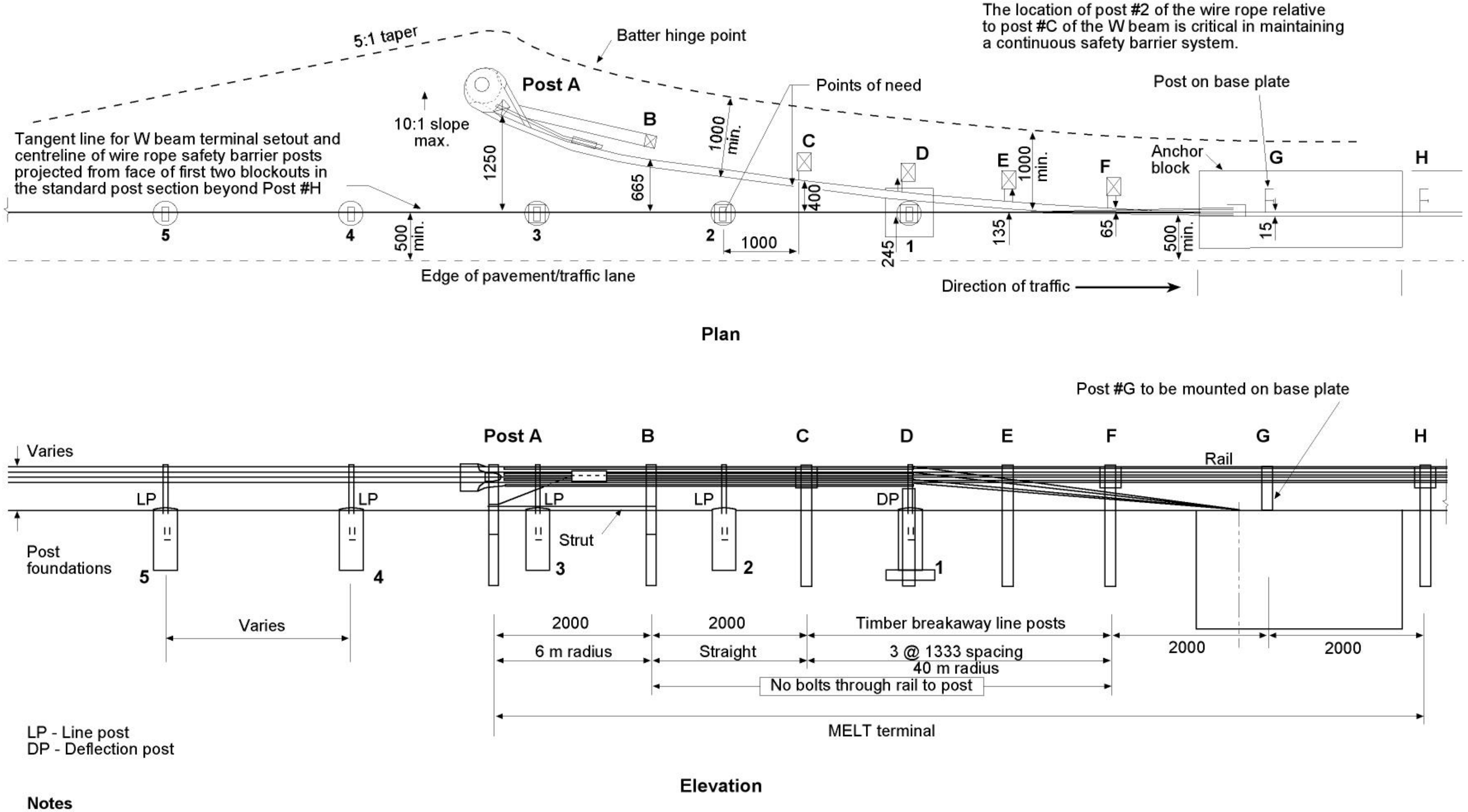
K.7 Wire Rope Safety Barrier to Semi-rigid Barrier

These transitions involve the wire rope safety barrier overlapping the W-beam or Thrie-beam barrier by a nominal longitudinal distance based on site conditions. Where space is available the barriers can be separated laterally so that they operate independently. An alternative acceptable arrangement (refer to Figure K 1) involves a design that ensures that each barrier does not adversely affect the performance of the other.

K.8 Wire Rope Safety Barrier to Concrete Barrier

The transition between WRSB and the concrete barrier also requires a longitudinal overlap and lateral separation adequate to accommodate deflections under impact. This transition has not been tested. However, the principle of having each barrier separated by a distance that should enable them to operate independently under impact is considered to be a sound and safe practice. An example of such a transition is shown in Figure K 2.

Figure K 1: An example of a transition between a wire rope barrier and W-beam barrier

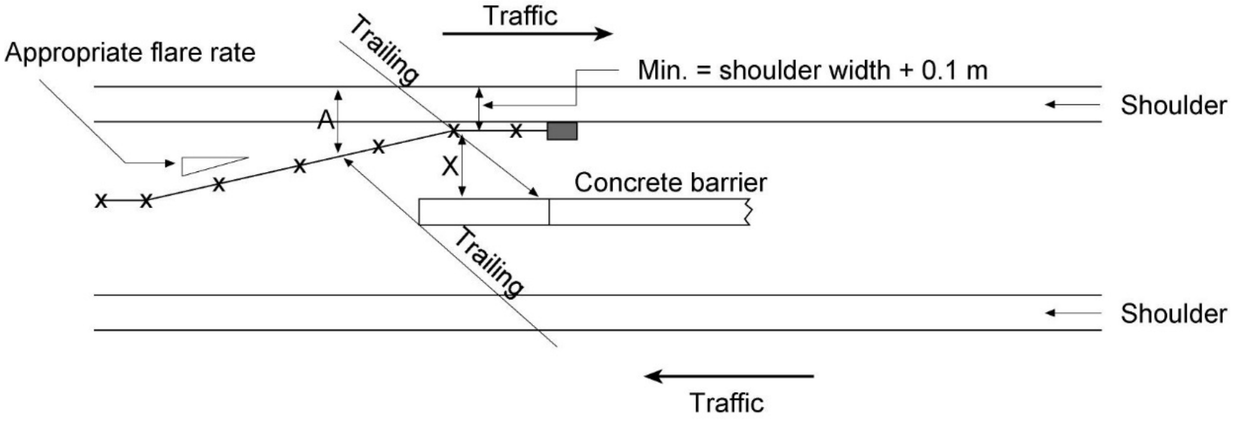


LP - Line post
DP - Deflection post

Notes
Posts in W beam safety barrier designated by letters A to H
Post in wire rope safety barrier designated by numerals 1 to 5

Wire rope safety barrier including anchorage detail
shall be installed as per manufacturers specificaions.

Figure K 2: An example of a transition between wire rope safety barrier and rigid barrier



Notes:

X is the dynamic deflection of the WRSB related to vehicles travelling along the road adjacent to the WRSB should they impact it.

A is the dynamic deflection for the WRSB for vehicle impacts from the opposite direction. The dynamic deflection 'X' varies depending on the wire rope barrier system used and the post spacing. Refer to Table 6.7 for an approximate guide to deflections of WRSB for concept design and planning purposes only.

Source: VicRoads.

Appendix L Barriers at Intersections

Intersections present special problems for barrier design because the corner radius is relatively tight and rather than impacting at acute angles typical of barriers adjacent to highway alignments, the impacts may be at any angle, including a right angle. Rigid and standard semi-rigid barriers will result in a high severity crash whereas a flexible barrier is unsuitable for such small radii. However, some designs have been developed to reduce the severity of such treatments.

The number of suitable choices becomes limited when continuing a barrier around a corner such as at the intersection of an overpass bridge and a freeway ramp. Special proprietary treatments may be suitable and should be considered. Wire rope safety barrier cannot be used on tight radius situations less than 200 m.

Intersection corners often accommodate road furniture such as signs, utility and signal poles and traffic control boxes, and any fixed hazards should be moved as far away from the traffic lane as practicable. The barrier systems that could be installed to shield these fixed objects may represent as much or even more of a hazard than the shielded objects themselves.

Where the intersection is adjacent to an overpass consideration should be given to the protection of the traffic on the road or rail below the overpass. If the volume of traffic on the lower road is great enough that an errant vehicle would be likely to be involved in a secondary crash, then it may be appropriate to provide a strong barrier on the corner to minimise this risk. A concrete barrier may be preferred in this situation.

Prior to adopting such a treatment, alternative options should be considered such as closure or relocation of the intersecting road. Sight distances to and from side roads must not be impeded by barriers.

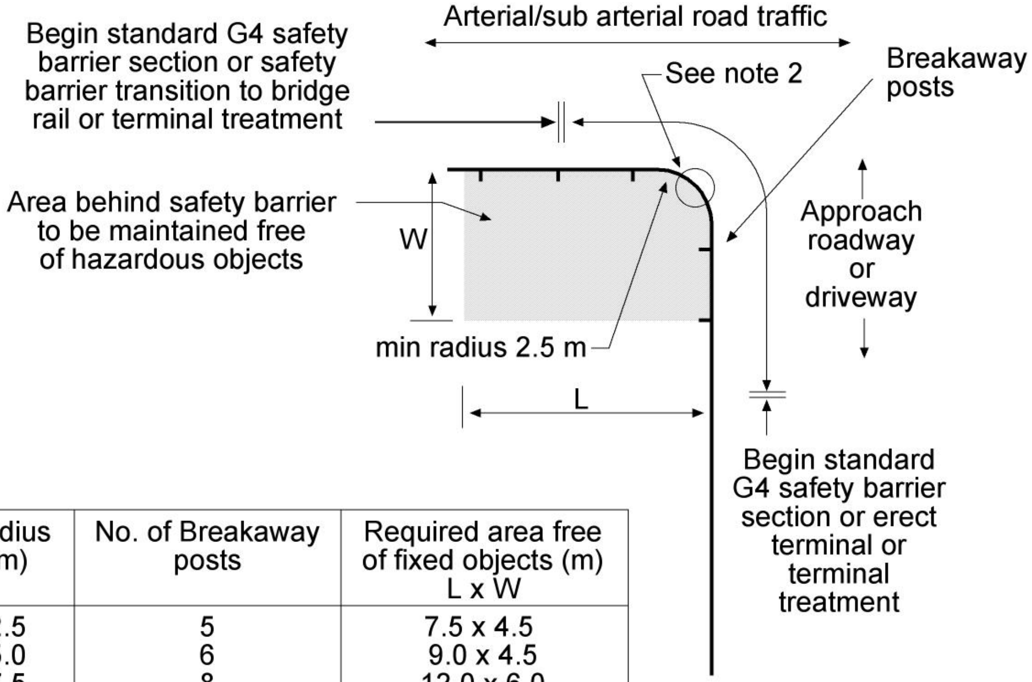
Figure L 1 and Figure L 2 show examples of designs for curved barriers at major road intersections. In order to be effective the treatments must be installed in accordance with the notes in the figures. The principle of the designs is that the barrier forming the corner radius is designed so that a design car impacting at a high angle is contained and decelerates at an acceptable rate of deceleration. This is achieved:

- through the use of break away posts at 2.0 m spacing
- by omitting blockouts
- by not providing washers on the mushroom-headed (coach) bolts connecting the rail to the blockouts.

An additional measure in the case of radii < 10 m is to omit the bolts that attach the rail to the post at the centre of the curve. This creates a curved rail that has been shown to contain vehicles that impact at high angles.

The requirements described above and noted in Figure L 1 and Figure L 2 are essential for safe operation of these curved sections. A designated run-out area behind the barrier should be kept free of hazardous objects.

Figure L 1: An example of a curved barrier at a major road intersection (radius 2.5 to 9.9 m)



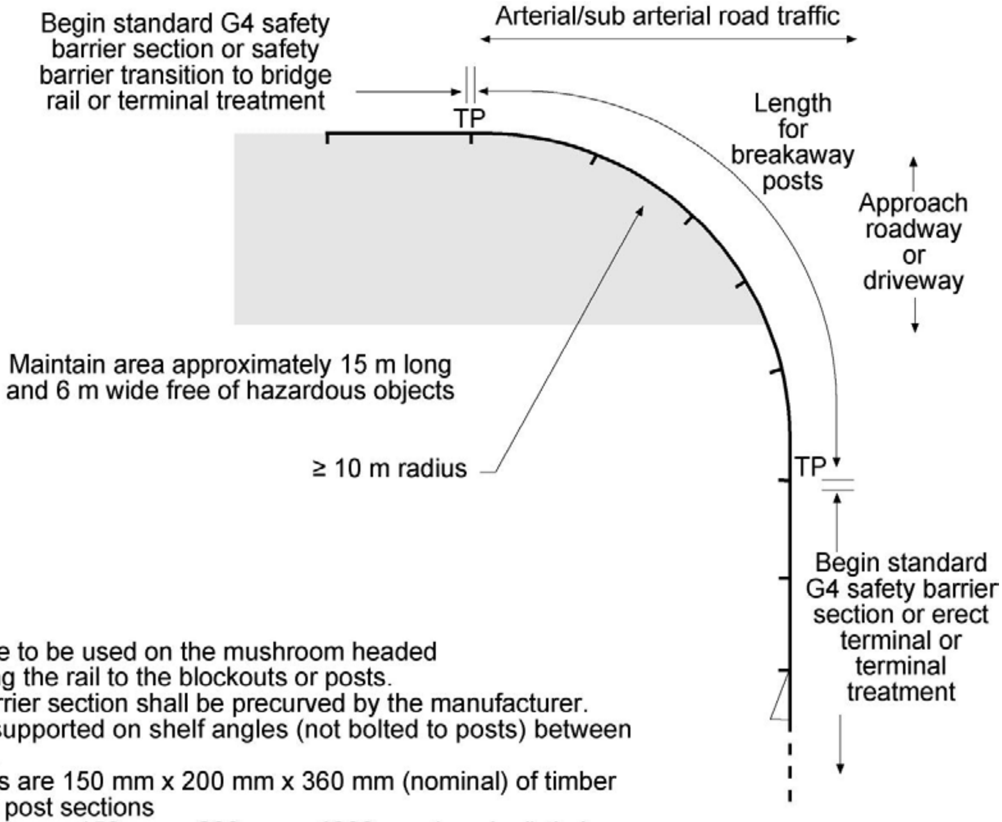
Radius (m)	No. of Breakaway posts	Required area free of fixed objects (m) L x W
2.5	5	7.5 x 4.5
5.0	6	9.0 x 4.5
7.5	8	12.0 x 6.0
10.0	11	15.0 x 6.0

Notes:

1. No washers are to be used on the mushroom headed bolts connecting the rail to the blockouts or posts.
2. The rail is not bolted to the post at the centre of the nose as shown.
3. The curved barrier section shall be precurved by the manufacturer. Curved rail is supported on shelf angles (not bolted to posts) between tangent points.
4. Timber blockout pieces are 150 mm x 200 mm x 360 mm (nominal).
5. Breakaway posts are 150 mm x 200 mm x 1800 mm (nominal) timber posts, (species to suit region or conditions) or steel posts with slip base.
6. Posts are spaced at 2000 mm centres.
7. AS/NZS 3845 gives details of G4 configuration.

Source: RTA (1996).

Figure L 2: An example of a curved barrier at a major road intersection (radius ≥ 10 m)



Notes:

1. No washers are to be used on the mushroom headed bolts connecting the rail to the blockouts or posts.
2. The curved barrier section shall be precurved by the manufacturer. Curved rail is supported on shelf angles (not bolted to posts) between tangent points.
3. Blockout pieces are 150 mm x 200 mm x 360 mm (nominal) of timber or steel charlie post sections
4. Breakaway posts are 150 mm x 200 mm x 1800 mm (nominal) timber posts, (species to suit region or conditions) or steel charlie posts with slip base.
5. Steel posts are spaced at 2000 mm centres.
6. AS/NZS 3845 gives details of G4 configuration.

Source: RTA (1996).

Commentary 1

Section 1.3 emphasises the need to implement a safe system approach to road safety and describes the contribution that roadside design can make to achieve a better road safety outcome.

Section 3 supports this approach by discussing the importance of designing a safe road environment in which risk to road users is reduced or eliminated and the damage to vehicles and their occupants is minimised.

Section 3 also stresses the importance of providing a consistent design that will enable drivers to remain on the road. It advises that this may be achieved by carefully considering the way in which design parameters are combined, the types of vehicles that share the road and many other factors such as those described below and those discussed in Commentary 2. Some of the following factors are not specifically related to design but are important in relation to the management of road assets and the need to provide traffic management devices to support a road design initially and to support traffic movement and safety into the future.

Key factors that may contribute to run-off-road crashes are:

- Road geometry, including sight distance. Vehicles are more likely to leave the road at curves that have small radii or inadequate pavement crossfall, particularly at curves with radii inconsistently smaller than those of preceding curves or at curves with restricted approach sight distance.
- Traffic volume and speed. Drivers are more likely to leave the road when performing avoiding manoeuvres on high-speed, high-volume roads, especially two-lane rural roads that have limited overtaking opportunities.
- Driver attentiveness, fatigue and awareness of road environment. Drivers who are tired, inattentive or unfamiliar with the road are more likely to leave the road than alert drivers. Thus long distance routes in monotonous terrain or roads that are inconsistent with the terrain require special consideration.
- Adequacy of visual cues of road alignment, including delineation. Lack of adequate edge delineation or misleading cues because of gaps in vegetation or lines of service poles may increase the risk of drivers leaving the road.
- Number and frequency of decisions required of the driver. Drivers are more likely to make mistakes and leave the road in complex situations requiring many decisions in rapid succession, especially if visual cues are insufficient or misleading.
- Road surface condition. Drivers are more likely to leave the road if a large part of their attention is devoted to negotiating a poor road surface, or if they suddenly encounter loose or slippery surfaces.
- Weather. Rain, frost, snow, fog, wind gusts and sun glare reduce the effective control drivers can exert on the paths of their vehicles and thus increase the risk of encroachments.
- Mechanical failure.

However, the likelihood of a vehicle leaving the road may be minimised by implementing appropriate measures.

Commentary 2

This commentary provides further discussion on road design elements and considerations that can influence the ability of drivers to travel safely on roads. It expands on the summary provided in Section 3.

C2.1 Combinations of Design Parameters

The adoption of lower order values for a number of design parameters in combination may create an unsafe design even though the individual design parameters are in compliance with guidelines. For example, combining a minimum radius horizontal curve with a minimum length vertical curve and narrow lanes may produce a design combination that has a low factor of safety, even though the individual elements comply with guidelines.

Designers should ensure that the combination of design elements makes it easy for drivers to keep their vehicles on the road, especially at night and in inclement weather. Particular attention needs to be paid to combinations of:

- vertical alignment
- horizontal curvature
- lane widths
- shoulder width
- sight distance
- medians
- road surface
- road surface drainage
- delineation
- verges.

Considerations on these design elements are provided in Table C2 1.

Table C2 1: Considerations in relation to designing roads for safety

Element	Considerations
Vertical alignment	Flat grades: • Allow all vehicles sharing a road to travel at the same speed. • Vertical grades of zero to 3% have little effect on the operation of all vehicles. • Uphill grades: • Steep grades become prohibitive for heavy vehicles. • Where steep grades are required, the design should minimise their length. • Grades in excess of 6% have a significant effect on heavy vehicles for travel uphill. • Vehicle speed differences also contribute to queuing, which is frustrating to drivers in the queue. • Where vertical curves occur in conjunction with horizontal curves extra care in design needs to be taken. Vertical curves or changes in grade may impede sight distance. • Downhill grades: • Grades in excess of 6% have a significant effect on heavy vehicles for travel downhill. • Long downhill grades increase the risk of a crash due to brake failure. • Very long downgrades, particularly those containing horizontal curves and reverse curves, cause vehicles (especially heavy vehicles) to suffer brake fade, and reach critical roadside features at such high speeds and impact angles that roadside protection is very difficult or impossible, even with the best road safety barriers. General: Steep grades cause different vehicles to travel at different speeds, introducing a higher risk of rear-end crashes. Where it is necessary to provide long steep grades, consider providing: • passing bays and descending lanes to allow light vehicles to overtake slower moving vehicles safely • safety ramps and arrester beds to bring a runaway vehicle to rest. These facilities are important where there is a high proportion of heavy vehicles. Adequate drainage must be provided to prevent water pooling on the road surface during normal levels of rain. Longitudinal drains need to have adequate fall, generally not less than 0.5%.
Horizontal alignment	Design for a radius as large as the landscape allows as a first step in providing a driveable path. Provide a consistent alignment standard over the relevant section of road with well-designed transitions where reductions from generous to tighter alignments are necessary. For a vehicle to travel around a bend at a certain speed, the horizontal friction between the vehicle and the road pavement must be sufficient to counteract the inertial force that tends to maintain the vehicle's initial direction. Provide localised curve widening where required (refer to the *Guide to Road Design – Part 3: Geometric Design* (Austroads 2009b). Extra lane width at curves maintains an acceptable clearance between vehicles. Road pavement widening may be required at curves depending on curve radius, lane width and vehicle sizes for the following reasons: • A vehicle (particularly a heavy vehicle) traversing a curve occupies more lane width than when travelling straight. • When a driver steers through a curve, the vehicle does not maintain the same lateral road position that it did on the straight. Some deviation from the ideal path must be expected. Both of these factors reduce the clearance between opposing vehicles and increase the risk of collision. Recommended curve widening for various categories of roads is given in the *Guide to Road Design – Part 3: Geometric Design* (Austroads 2009b).

Element	Considerations
Lane width	Traffic lane width influences the ease with which vehicles can operate in that lane. Higher traffic volumes and higher speeds require wider lanes to allow more space between passing vehicles, and between vehicles and any roadside objects. If lane width is insufficient, vehicles may be forced into the roadside because of: • the blast of air pressure created by large vehicles passing in the opposing traffic lane • vehicles (particularly articulated vehicles), in the adjoining or opposing traffic lane swaying into the incorrect traffic lane. In some instances, lightweight vehicles have been sucked into the slipstream of passing vehicles, and the evasive action by drivers of the lightweight vehicles has caused the lightweight vehicles to encroach into the roadside. Recommended lane widths for various categories of roads are given in Austroads (2009b).
Shoulder width	Shoulders not only provide a lateral support for the road pavement but also provide additional separation between traffic and roadside objects. Shoulders are not intended for regular travel, but allow drivers more room to bring their vehicles back under control after inadvertently leaving the traffic lane. Sealed shoulders are desirable to assist errant vehicles to recover should they leave the travelled path and also reduce the incidence and severity of run-off-road crashes. The decision to seal shoulders depends on the road category, traffic volume and the crash record. The width of shoulder sealing depends on traffic speed, volume and composition, environmental conditions and the nature of the roadside area. Sealing part of the shoulder to reduce pavement drop-off may reduce errant vehicle incidents. Recommended shoulder widths for various categories of roads are given in Austroads (2009b).
Sight distance	Adequate sight distance should be provided to allow road users to safely negotiate the road. Sight distance can be affected by road geometry (horizontal and vertical alignment), terrain (particularly inside of horizontal curves) and roadside objects (such as trees and signs). At a horizontal curve, drivers need to be aware of the road curvature ahead and be able to react and slow down (if necessary) to safely navigate the curve. Drivers should be able to see a sufficient length of horizontal curve in order to judge its curvature and safely navigate the curve. A curve should not commence just over the crest of a hill. However, where this situation is unavoidable, measures should be taken to ensure that drivers are made aware of the alignment ahead (e.g. sight distance, warning signs, delineation). Roadside features such as cutting slopes and vegetation may limit sight distance and should be modified or removed to ensure sufficient stopping sight distance on curves. If this is not practical, the speed limit may have to be reduced through such sections to compensate. It is important that roadsides be maintained to ensure that sight distance requirements are sustained, for example by regularly pruning trees and cutting grass. Where substandard curves are unavoidable, consider cutting benches in high batters to improve sight distance. Recommended sight distance requirements are given in the Austroads (2009b).
Medians	Median width influences the crossover crash rate on medians without road safety barriers. Cross-median crashes are often high severity, head-on crashes (Knuiman et al. 1993). Jurisdictional policy should be consulted regarding the current approach for median design and protection by road safety barriers.

Element	Considerations
Road surface	A road surface should to be constructed and maintained to a sufficient standard that ensures adequate skid resistance. The skid resistance of a particular surface results from the surface texture and the presence of moisture (e.g. a pavement surface that holds water instead of draining properly can contribute to vehicles aquaplaning). The condition of an existing pavement can be determined by conducting skid resistance measurements as well as assessing the level of rutting and occurrence of potholes. Measurement of skid resistance and rutting can be undertaken using a number of methods, some of which are highly automated and efficient. The decision to act on the results of such measurements is left to the experienced practitioner; however, a guide to the use of skid resistance values can be found in the *Guide to Asset Management – Part 5F: Skid Resistance* (Austroads 2009k) Roads with a comparatively high volume of heavy vehicle traffic (usually major link routes) may require a higher standard of construction and maintenance than roads that predominantly carry light vehicles such as cars and vans. Unevenness and rutting of road surfaces can cause motorcyclists to abruptly change from their intended cornering line which may result in crashes.
Road surface drainage	A number of different aspects need to be considered with regard to drainage. These include: • drainage of the road pavement by providing adequate grade and crossfall so that the pavement is able to drain and pooling of water is avoided, which allows maintenance of skid resistance • appropriate infrastructure to collect and transfer the water from the pavement, which may include kerb and channel or table drains • a road reservation that can accommodate water run-off from adjacent land uses. Drainage design at the road design stage requires consideration of flood estimation. If constructed along a flow path, a road may need to be designed to accommodate the run-off from adjacent land for a flood event (refer to the *Guide to Road Design – Part 5: Drainage Design* (Austroads 2008b). Where concrete barriers are installed it is essential that adequate provision is made for water to drain from the road (i.e. under or through the barrier) so that ponding of water does not occur adjacent to the barrier.
Delineation and signposting	The more unexpected aspects of a road's geometry will require additional signage and delineation to convey information to drivers in accordance with AS1742.2 – 2009 or Transit NZ (2008) and jurisdictional guides. Guideposts show the edge of the road and enhance delineation of the path to be travelled by drivers. They should be installed at a uniform distance from the edge of the road and should be fitted with delineators. On narrower or lower volume roads where there is insufficient road width to mark a centre line, guideposts may be the only delineation provided. In areas above the snow line, there is a risk that raised pavement markers could be damaged by snowploughs or obscured by snow. For this reason, it is recommended that orange snow poles are used for delineation. Snow poles are designed to protrude above snow drifts and their orange colour aids visibility in snow.
Verges	It is preferable that verges and roadside areas within the clear zone are free of hazards and are traversable. Where this is not possible a risk assessment should be undertaken to determine the most appropriate treatment (e.g. removal, modification or shielding of the hazard).

C2.2 Consistent Design Environment

Safety on roads is closely related to the driver's ability to anticipate events and react to them. Where drivers are uncertain of what lies ahead their perception and reaction times will be longer than in situations where a consistent design environment gives them confidence in what to expect.

A safe road design has on-road and roadside features that clearly show drivers the path that a road takes and helps them keep their vehicles in the running lane. Road design should therefore be based on appropriate driver characteristics with the objective of making it as easy as possible for the driver to keep the vehicle on path. This may be straightforward if the landscape is always suited to the desired path of the road and there is no space or financial constraints, but this is rarely the case.

Roads must be contained within the topography in a cost-effective way and this may lead to situations that require departures from the standard. In such cases it becomes necessary to provide additional features designed to help drivers follow the line of the road (e.g. vegetation, signs and delineation).

In order to give motorists the best chance of keeping their vehicles on the road, it is necessary to provide a geometric design conducive to safe travel. The principal factor influencing a vehicle's ability to traverse and remain on a particular section of road is the speed of the vehicle. Accordingly, it is necessary to take into account the operating speed of a road section when setting such parameters as curve radii, lane widths, shoulder widths, seal types, drainage and vertical alignment. Designers should refer to the Guide to Road Design – Part 3: Geometric Design (Austroads 2009b) for guidance on geometric design elements.

Design consistency needs to be considered in relation to all relevant design elements and considerations. Key examples are summarised in Table C2 2.

Table C2 2: Key considerations for consistent design

Consideration	Comment
Cross-section consistency	Cross-section dimensions should be compatible with horizontal and vertical alignment. (e.g. improving cross-section dimensions while retaining poor alignment can create the hazardous illusion that the road can be driven at a higher speed than is safely possible). Where cross-sections change (e.g. where a divided road link joins an undivided link) generous tapers and advance signage should be provided to make the change obvious.
Operating speed consistency	Differing speeds in the traffic stream can be caused by: • an unclear road hierarchy • drivers being unsure of what lies ahead • drivers having differing levels of confidence in negotiating road geometry with low design values. Road networks that do not provide a hierarchy of road functions can cause speed differential because local, short-trip traffic is mixed with high-speed through traffic. The greater and more frequent the speed differential between vehicles, the greater is the chance of crashes.
Driver workload consistency	Abrupt changes in driver workload may influence crashes because driver response to situations may be slow or inappropriate. If driver workload is: • too low then drivers may become inattentive • too high then drivers begin to shed information (look but not see). Some of the shed information may be critical (e.g. other vehicles entering the travel path). Increases in driver workload may be caused by: • limited sight distance • inconsistent design, causing surprise (e.g. a sharp curve at the end of a long straight) • driver being unfamiliar with the road (e.g. on infrequently travelled highways). Design aspects that affect driver performance to be considered include: • Avoid low arousal straight alignments. A curve with a very large radius (i.e. almost straight) will be monotonous for drivers leading to a lack of concentration on the steering task). • Avoid the concentration of decisions into a short time frame as this will create information overload (e.g. excessively complex intersection layouts). • Stage speed changes (e.g. change the design speed of geometry in steps rather than implement abrupt changes from high speed to low speed). • Provide rest areas to cater for fatigued drivers.

C2.3 Vehicle Mix Considerations

Total travel by trucks is growing at a rate twice that for cars and recent traffic growth estimates indicate that this growth is likely to continue for at least another 15 years. A significant proportion of trucks are articulated heavy vehicles. It is important to consider the impact and additional risk of a higher than normal percentage of heavy vehicles.

The consequences of crashes involving heavy vehicles are much greater than for cars. A run-off-road crash involving a truck may kill or injure the truck driver and passengers, but in a catastrophic crash involving a truck and cars the consequences to the car occupants and other people outside the truck (e.g. pedestrians) are the major effects.

In the case of a bus, a road crash is more likely to involve casualties of persons outside the bus. However, a catastrophic crash involving a bus may kill or injure many of the passengers in the bus.

When designing for heavy vehicles, designers should examine the road design parameters shown in Table C2 3.

Table C2 3: Road design parameters for consideration in relation to heavy vehicles

Parameter	Consideration
Grades	Weight and low power-to-weight ratio cause heavy vehicles to slow below the speed limit on grades and cause problems with faster traffic.
Acceleration lanes	Heavy vehicles accelerate slower than cars and need longer to reach a target speed. Forcing trucks to merge with main traffic lanes too early can adversely affect faster traffic. Lanes that merge with high-speed roads should be long enough to allow for heavy vehicle acceleration. A downgrade on these lanes will help.
Curve radii	Considerations include: • Longer vehicles may encroach into the adjacent lane on corners that have small radii or narrow lanes. • The roll stability of heavy vehicles is less than cars, because of their weight and higher centre of gravity. A heavy vehicle is more likely to roll than to skid in a tight corner. • Designers should provide the largest curve radii consistent with the environment.
Stopping and sight distances	Although the eye height of a heavy vehicle driver is higher than that of a car driver, truck stopping distances are considerably longer because of the relatively inferior braking of heavy vehicles thus requiring longer sight distances.

C2.4 Other Factors Contributing to Errant Vehicles

Other road design issues that may contribute to errant vehicles are outlined in Table C2 4.

Table C2 4: Other factors contributing to errant vehicles

Factor	Contribution to
Lack of overtaking lanes	Drivers overtaking ill-advisedly and: • causing vehicles to swerve into the roadside to avoid head-on crashes with oncoming vehicles • actually causing head-on crashes • causing vehicles to hit objects in the median.
Unsealed shoulders	May cause a vehicle to lose control and travel further into the roadside making it more likely to impact a hazard or overturn.
Rounded pebbles encroaching on sealed or unsealed shoulders	

Factor	Contribution to
Clear roadside areas with surface that is either rutted or covered with rounded pebbles	
Pavement edge drop-off	Vehicles becoming errant or over-correcting to regain the pavement and swerving across the road into oncoming traffic.
Crack filling with slippery, hard, raised lines	Loss of friction and loss of control. Motorcycles being thrown off line. Forming slippery, hard, abrupt humps causing motorcycles to bump.
Settlement of the roadway behind bridge abutments	Deep depressions in the roadway and sharp transverse edges at abutments, causing a change in the line of travel.
Road patching with uneven raised or depressed edges and surfaces	Motorcycles having to change their line of travel.
Mounding and/or cracking of road surface due to tree roots	
Raised service covers (water, sewerage communications etc.)	
Non-standard raised pavement markers	
Gravel on the road	Loss of friction causing vehicle slide.
Sun glare and dust	Blinding of drivers causing swerving, or ill-advised overtaking and: • causing vehicles to swerve into the roadside to avoid head-on crashes with oncoming vehicles • causing vehicles to hit objects in the median.
Cross-winds	Throwing vehicles seriously off line, causing a crash.
Overhanging vegetation	May: • obstruct sight distance so the driver has no warning of the road alignment ahead or of slower-moving vehicles in the lane ahead • be struck by a motorcycle rider’s head. This in turn can cause: • vehicles to brake excessively and veer into the roadside • rear-end crashes.

Commentary 3

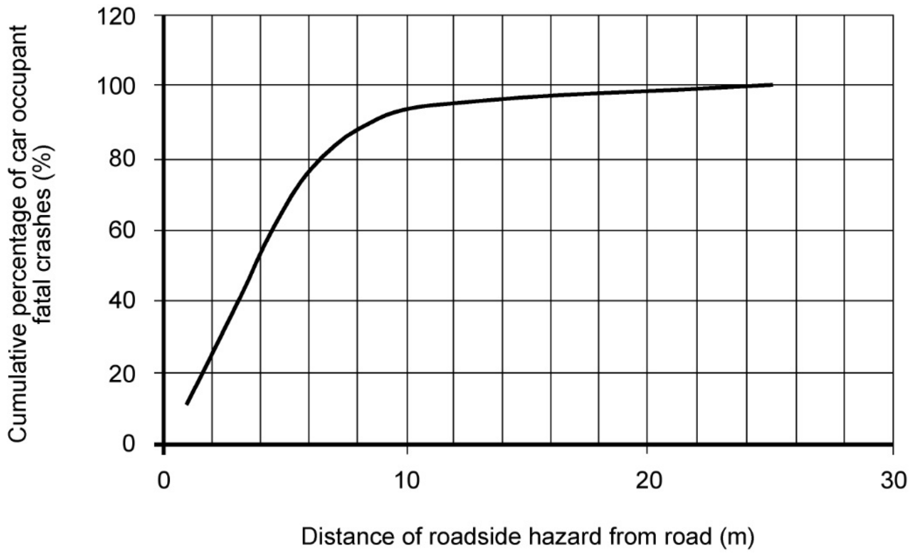
C3.1 Background to Clear Zone Width and Hazard Corridor Width

The clear zone concept was first introduced in the USA in the 1970s. Reports on studies into roadside run-off-road crashes (e.g. Hutchinson and Kennedy 1966) stated that an unencumbered 9 m wide corridor beside the travelled lane permits about 80% of the out-of-control vehicles leaving a high-speed roadway to recover. It is understood that the original dimensions were obtained from incidents at the US General Motors proving ground. This width did not take into account roadside geometrical factors that may determine the extent of vehicle run-off-road incidents, such as slopes, bends or individual road characteristics. A review of accident statistics in the USA showed that these factors do need to be considered in determining recovery width.

Kloeden and McLean (1999) conducted a study of roadside hazard involvement in fatal and severe injury crashes in South Australia. Analysis of fatal crash records for the 12 year period from 1985 to 1996 revealed that 95% of fatal crashes involving a collision with a roadside object occurred between 0 and 10 m adjacent to the road (Figure C3 1). However, the impact of speed zone and traffic volume as factors influencing crash frequency was not considered.

These studies demonstrate that a significant percentage of errant vehicles come to rest beyond a 9 m to 10 m clear zone, and that some errant vehicles will crash into hazards beyond a 10 m clear zone. Designers should appreciate that 'clear zone' is a concept, that the computed distances are intended only as a guide, and that as a percentage of errant vehicles are likely to travel beyond the desirable clear zone, hazards beyond the clear zone should be considered and minimised wherever feasible.

Figure C3 1: Distance from edge of traffic lane to roadside hazards causing car occupant fatal crashes



Source: Derived from Kloeden & McLean (1999).

The selected clear zone width is a compromise, based on engineering judgement, between what can practically be built and the degree of protection afforded the motorist (NYS DOT 2003). In applying engineering judgement it is essential to properly account for the specific characteristics and risks associated with particular sites. For example, a deep continuous precipice just beyond the clear zone on a high-volume, high-speed road would require shielding because of the high exposure and severity whereas an isolated point hazard just within the clear zone of a low-volume road may be judged not to require treatment.

On some projects it may be appropriate to define a single clear zone width for the entire length of the project. However, during the feasibility and detail design stages it is desirable that the widths be varied in a step-wise fashion to take account of site factors and in accordance with the widths that can be reasonably achieved.

Commentary 4

The identification of hazards should be based on a risk assessment process. However, where existing roads are being considered crash records can be particularly valuable (when adequately supplemented by site information) for identifying hazards and considering treatment of those hazards. Many factors may need to be examined as possible contributory causes even when they are not the primary cause of a crash, as they may indicate that treatments other than a road safety barrier are appropriate at particular sites. Detailed guidance on investigating crash locations, diagnosing crash problems and developing solutions is contained in the *Guide to Road Safety – Part 8: Treatment of Crash Locations* (Austroads 2009a).

Warrants for the consideration of sites for treatment are often applied in road safety programs and may change over time. As a general guide it is generally considered that any roadside object or location that has had at least three crashes (resulting in a casualty or a vehicle being towed away) over a five year period should be considered for remedial treatment.

Commentary 5

Roadside hazards may be classified as ‘point hazards’ or ‘continuous hazards’, depending on their physical extent along the roadside. Each classification includes many specific potential hazards, some of which are listed below.

Point hazards

Point hazards are defined as permanent installations, of limited length, that can be struck by vehicles running off the road. Because of their limited extent, point hazards should usually be removed from clear zones, rather than being shielded with a road safety barrier. Attention should be focussed on objects that are both within and beyond the computed clear zone width particularly where site conditions suggest that a greater clear zone would be desirable. The following items, when located within clear zones, are examples of point hazards:

- trees over 70 to 100 mm in diameter depending on species
- bridge end posts and piers
- large planters boxes
- hazardous mail boxes or landscape features
- non-break away signs
- inappropriate slip-bases on signs
- protruding footings (including those for break away signs)
- non-traversable driveway headwalls
- non-traversable culvert headwalls
- fixed objects in open drains
- utility poles
- rigid road lighting poles
- walls or corners of walls
- hydrant bases more than 100 mm high.

It should be noted that while trees less than 70 – 100 mm in diameter within the clear zone are not considered to be point hazards, they should still be removed from the clear zone as they can grow to become hazards in the future. Multiple trees less than 70 – 100 mm in diameter may also be hazardous if they are spaced less than 2 m apart. This is relevant to existing vegetation and substantial shrubs that may be planted as part of a landscaping treatment.

Continuous hazards

Continuous hazards differ from point hazards in that they are of considerable length and therefore it is generally less practical to remove or relocate them. When located within the clear zone they are considered to be hazards. However, they may also be a significant hazard when situated beyond the clear zone. The length of the hazard increases the likelihood that an errant vehicle will crash into it, and some hazards (e.g. cliffs) have a high crash severity regardless of the speed of the errant vehicle. Examples of continuous hazards include:

- dense woods
- rows of large trees
- steep embankments (i.e. that have a critical slope or non-recoverable slope)
- rock outcrops or boulders intermixed with trees
- rock cuttings
- cliffs or precipitous drop-offs
- bodies of water, including streams and channels
- unshielded hazards such as cliffs or bodies of water that are beyond the desired minimum clear zone, but are likely to be reached by an errant vehicle
- retaining walls
- presence of kerbs with a vertical face (i.e. barrier kerbs) over 100 mm high on roads with operating speeds of 80 km/h or greater
- fences with horizontal rails that can spear vehicles.

All hazardous roadside features should be considered high priority if they are associated with accident clusters or a greater-than-average history of crashes. Opposing traffic may also be regarded as a continuous hazard that should be shielded with a median road safety barrier depending on the traffic speed, traffic volume and median width.

Commentary 6

The paper *Vehicle Impacts in V-Shaped Ditches* in the Transportation Research Record 1797 Paper No. 02-3950 (Thomson & Valtonen 2002) describes the results of some crash testing of drain shapes which indicates that, depending on the angle of departure of the vehicle from the road, shapes outside of those shaded in Figure 4.10 and Figure 4.11 in the *Guide to Road Design – Part 3: Geometric Design* (Austroads 2009b) are traversable.

Thomson & Valtonen (2002) reports that the collision violence of vehicles travelling in a V-shaped ditch was not appreciably worse than the loading measured in standardised testing of road restraint systems, as long as a rollover did not occur. The rollovers observed tended to be quite violent even for the lowest speed tests (80 km/h).

A significant risk not measured in these (or similar) tests was the consequence of a vehicle travelling over the backslope and continuing into the roadside terrain. The backslope used in these tests was 1 m higher than the road, which was not sufficient to contain vehicles to the ditch. The speed was observed to be not significantly reduced as the vehicle exited the ditch. Often the vehicle was airborne as the backslope acted as a ramp. Subsequent impact with a pole, tree, or rock located beyond the ditch could have severe consequences for the vehicle trajectories observed in the tests.

Commentary 7

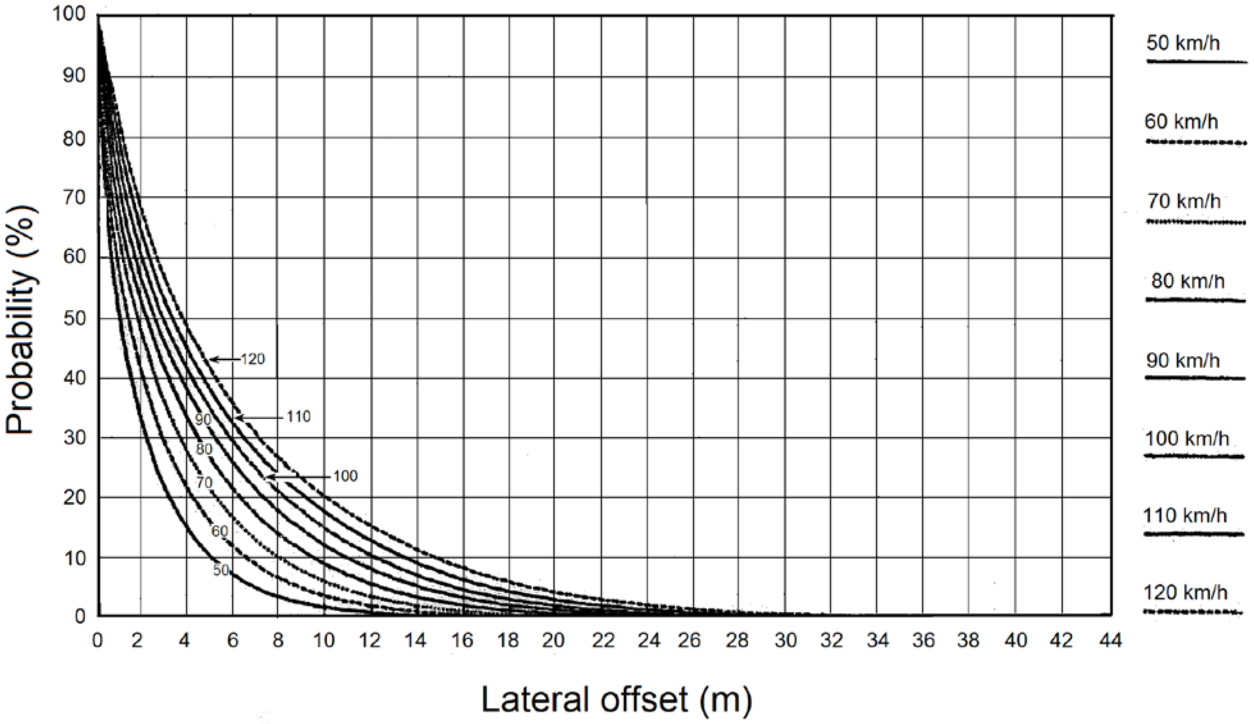
The Road Safety Risk Manager (RSRM) has been developed to provide road safety professionals with a tool to proactively assess road safety hazards and treatments for the purpose of prioritising actions. The tool adopts a risk management approach, with the ultimate aim of maximising the risk reduction on the road network for a given budget. RSRM provides a method to evaluate treatments and assist designers in making optimal investment decisions. It enables relative risks to be examined for different treatments at a site, including those associated with proposals to provide road safety barriers.

RSRM is specifically focussed on the prioritisation of appropriate treatments. It is not a replacement for sound engineering judgement. The method calculates a risk reduction to cost ratio (discounted risk reduction/discounted costs) and uses this as the basis for prioritisation of treatments.

Commentary 8

If a roadside feature lies within the clear zone for a particular road segment there is an increased probability that an errant vehicle may collide with the feature. This probability increases as the distance from the edge of the travelled way to the feature is reduced. Figure C8 1 shows a suite of curves used by the Queensland Department of Transport and Main Roads to determine the probability of a vehicle reaching a hazard. The curves depict the relationship between vehicle speed and the probability of an errant vehicle travelling a particular lateral distance from the travelled way.

Figure C8 1: Probability encroachment curve



Source: QDMR (2005).

Commentary 9

Australian and Swedish analysis (Nilsson and Prior 2004) concludes that installing road safety barriers on narrow medians will result in:

- a 35-50% reduction in the number of fatalities
- a 30-45% reduction in the number of severe injuries (assuming a similar distribution between mild and severe injuries in Australia as in Sweden (approximately 1 in 3 or 1 in 4))
- no increase, or only slight increase, in the number of mild injuries
- a 30% increase in the number of vehicle damage/non-injury accidents due to the fact that previously harmless median crossings become impacts with the road safety barrier.

Commentary 10

A minimum median width for wire rope road safety barriers adopted by the RTA in NSW has been provisionally set at 1.6 m to contain damaged posts and cables within the median. Installations on narrower medians would need to be supported by very efficient incident clearance procedures to ensure that cables and posts from damaged wire rope barriers are quickly removed when they encroach into the carriageway.

The minimum width for concrete or semi-rigid steel median barriers in severely constrained situations is the width of the barrier plus 0.5 m clearance on each side.

Commentary 11

Whilst it is preferable to have a smooth, flat face on crash barriers there is evidence to suggest that some vertical relief to enhance the appearance of barriers is acceptable (FHWA 2002). Based on a review of submitted information and test results the Federal Highway Administration (FHWA) accepted that the following guidelines for concrete barrier texturing are acceptable and would not adversely affect the NCHRP Report 350 test level of the barrier to which a texture or pattern is applied.

On the basis of the FHWA acceptance, road authorities may consider the use of textured surfaces on concrete barriers provided that they comply with the following requirements:

- Sandblast textures with a maximum relief of 9.5 mm.
- Images or geometric patterns inset into the face of the barrier 25 mm or less and having 45 degree or flatter chamfered or beveled edges to minimise vehicular sheet metal or wheel snagging.
- Textures or patterns of any shape and length inset into the face of the barrier up to 13 mm deep and 25 mm in width.
- Any pattern or texture with gradual undulations that have a maximum relief of 20 mm over a distance of 300 mm.
- Gaps, slots, grooves or joints of any depth with a maximum width of 20 mm and a maximum surface differential across these features of 5 mm or less.
- Any pattern or texture with a maximum relief of 64 mm, if such pattern begins 610 mm or higher above the base of the barrier and all leading edges are rounded or sloped to minimise any vehicle snagging potential. No part of this pattern or texture should protrude above the plane of the lower, untextured portion of the barrier.

The FHWA approval also concluded that:

- Texture or pattern meeting the guidelines can be applied to all crashworthy single slope or vertical wall designs.
- It is clear from the crash test results that textured barriers can result in more vehicular body damage in a crash due to increased friction even if their crash performance remains within acceptable limits.
- Although the barriers tested were 1220 mm and 1422 mm tall, review of the crash and post-crash vehicle trajectories indicate that these guidelines may also be applied to vertical walls as low as 685 mm and to any single-sloped barrier at the standard 813 mm height or higher.
- These treatments may prove acceptable on New Jersey and F-shape concrete barriers if the treatment is applied only to the upper sloped face of the barriers, but some crash testing would be advisable to verify good performance with these shapes.

Commentary 12

C12.1 General

Section 6.3.4 discusses the lateral placement of road safety barriers in relation to the road. It also introduces the issue surrounding the placement of barriers on embankments, behind kerbs and on cutting slopes. When cars pass over embankment slopes, kerbs or cutting slopes their front bumper height may follow a trajectory that is lower or higher than the normal static bumper height.

The trajectory is important should it be necessary to locate a barrier within particular lateral limits with respect to the back of a shoulder or kerb of a road because the barrier may have to be set at a height (i.e. higher or lower than normal height if installed on a relatively flat surface) that will contain an errant car. If set too high an errant car may become snagged or pass under the barrier and if set too low an errant vehicle may vault over the barrier.

The *Guide to Road Design – Part 2: Design Considerations* (Austroads 2006b) discusses the concept of normal design domain (NDD) and extended design domain (EDD). It is emphasised that the placement of a barrier on embankment slopes, behind kerbs and on cutting slopes within the lateral distances described as ‘not recommended’ in Figure C12 4 falls within the realm of extended design domain.

In constrained locations at greenfield sites (and particularly at brownfield sites), it may not always be practical or possible to achieve all of the relevant NDD values (and practice). In these constrained locations, road authorities may consider the use of values outside of the NDD.

In applying this guide:

1. NDD values (and practice) given in the body of this guide should be used wherever practical.
2. Design values (and practice) outside of the NDD are only to be used if approved in writing by the delegated representative from the relevant road authority. The relevant road authority may be a state road authority, municipal council or private road owner.
3. If using EDD values, the reduction in standard associated with their use should be appropriate for the prevailing local conditions. Generally, EDD should be used for only one parameter in any application and not be used in combination with any other minimum or EDD value for any related or associated parameters.

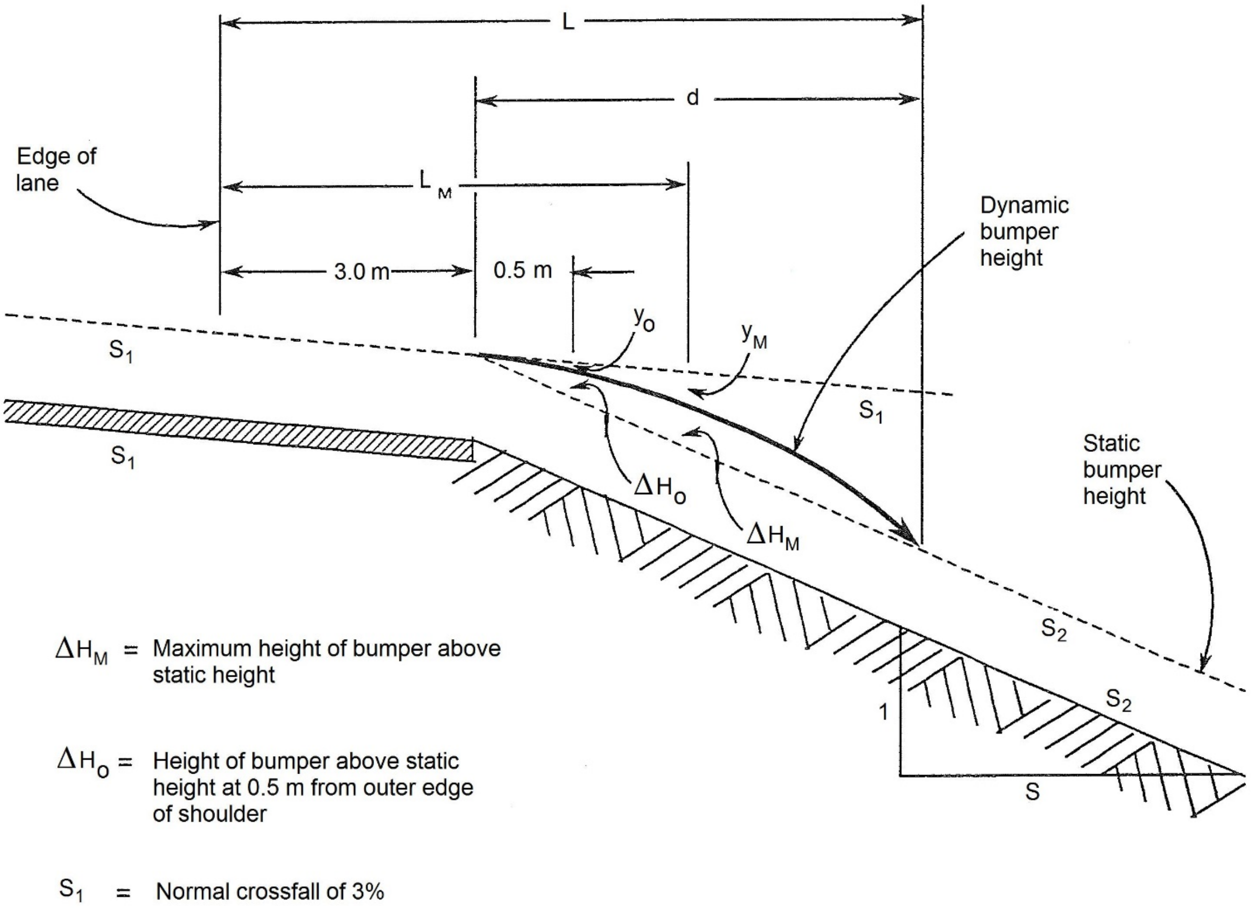
The following sections provide examples of vehicle trajectories over embankments, kerbs and cutting slopes. The source of the examples is Section 6 of the Roads and Traffic Authority of New South Wales *Road Design Guide* (RTA 1996). A summary of limitations on barrier location in these situations is provided in Section C12.5.

C12.2 Vehicle Trajectory Over Embankments

When vehicles pass over embankments, even at moderate speed, the bumper trajectory rises above normal bumper height, as illustrated in Figure C12 1, and this can cause a vehicle to vault over an incorrectly placed road safety barrier. The rise in bumper level is not significant for embankment slopes of 10:1 but becomes significant at steeper slopes. Road safety barrier should therefore be located between the traffic lane and the embankment hinge point. If this is not possible, the barrier may be placed up to 0.5 m beyond the hinge point.

If there is no alternative than to place a barrier on an embankment, it must be located beyond distance ‘L’ in Figure C12 1, the point at which the bumper returns to its static height. This distance varies with design speed and batter slope and an example of distances relating to specific embankment slopes and encroachment angles is shown in Table C12 1. It is also desirable that the batter be rounded at the hinge point to reduce the effect of the change in slope on vehicle dynamics.

Figure C12 1: An example of bumper height trajectory characteristics over fill embankments



Source: RTA (1996).

Table C12 1: An example of bumper trajectory data over embankments at 100 km/h

Encroachment angle (degrees)	Embankment slope S2 (S:1)	L (m)	ΔH_O (mm)	ΔH_M (mm)	L_M (m)	d (m)
25	10:1	5.0	30	30	4.0	2.0
25	6:1	6.8	60	130	4.9	3.8
25	4:1	9.2	100	340	6.1	6.2
25	3:1	11.5	140	650	7.3	8.5

Encroachment angle (degrees)	Embankment slope S2 (S:1)	L (m)	ΔH_O (mm)	ΔH_M (mm)	L_M (m)	d (m)
25	2:1	16.2	230	1550	9.6	13.2
15	10:1	3.7	10	10	3.4	0.7
15	6:1	4.4	40	50	3.7	1.4
15	4:1	5.3	90	130	4.2	2.4
15	3:1	6.2	130	240	4.6	3.2
15	2:1	8.0	210	580	5.5	5.0

Source: RTA (1996).

C12.3 Vehicle Trajectory Over Kerbs

When vehicles pass over kerbs at speed they are subjected to an upward force such that pitch and roll will be developed. The combination of these effects will cause the vehicle bumper to follow a trajectory that will lead it to being higher or lower than its normal position relative to the wheels and the bumper trajectory may rise above normal bumper height as illustrated in Figure C12 2, and this can cause a vehicle to vault over an incorrectly placed road safety barrier. Road safety barrier should therefore be located close to the back of kerb or at a sufficient distance further behind the kerb where the bumper height has returned to normal level.

The trajectory of the bumper depends upon the:

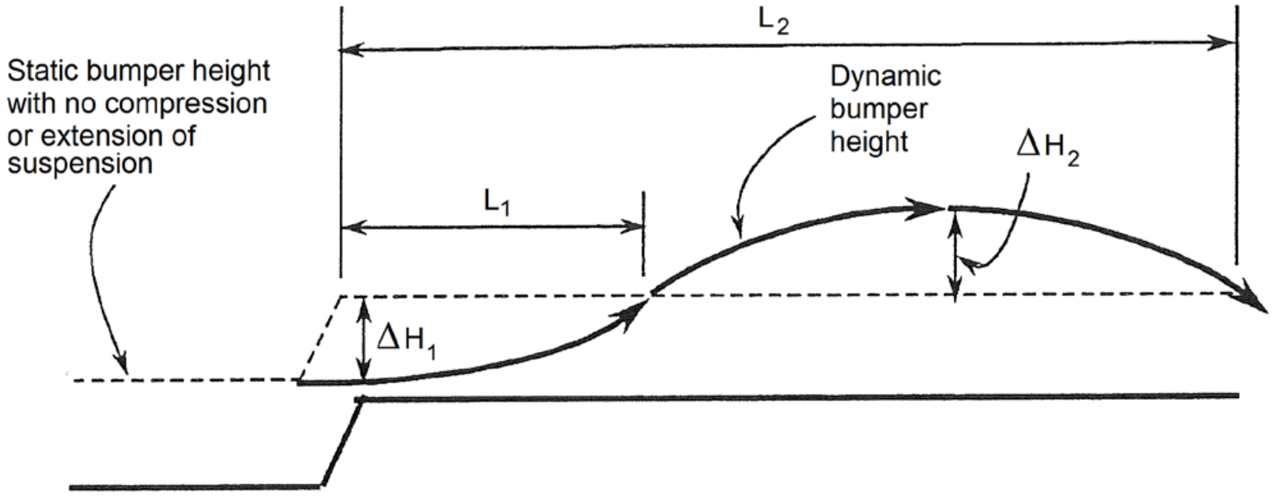
- size and suspension characteristics of the vehicle
- vehicle’s impact speed and angle
- the height and shape of the kerb.

Table C12 2 shows an example of data relating to Figure C12 2. However, it should be noted that the trajectory profile shown in Figure C12 2 and the data in Table C12 2 are not based on current vehicle fleet characteristics which may behave differently in traversing kerbs.

An understanding of the vehicle behaviour (i.e. bumper trajectory) is important in locating the road safety barrier because the:

- Lowering of a bumper may cause a vehicle to snag on the underside of the road safety barrier rail within the distance L1 in Figure C12 2.
- Rise of the bumper may cause it to ramp and vault over the rail. This effect (i.e. rise) is greater for barrier kerbs than for semi-mountable kerbs and can be in excess of 200 mm depending of the type of kerb, and the speed and impact angle of the vehicle.

Figure C12 2: An example of bumper height trajectory characteristics over kerbs



Source: RTA *(1996).*

Table C12 2: An example of bumper trajectory data over specific kerbs

RTA kerb type	Speed (km/h)	Angle (degrees)	L_1 (mm)	ΔH_1 (max) (mm)	L_2 (mm)	ΔH_2 (max) (mm)
SA/SM/SL(1)	80	10	575	150	1550	140
	80	25	1275	150	4500	180
	100	10	750	150	1750	190
	100	25	1625	150	5400	190
SE/SF(2)	90	12.5	1525	140	2900	50
	90	20	1950	165	4200	85
	100	12.5	1775	165	3750	85
	100	20	2075	160	4950	85

1. These are forms of barrier kerb.

2. These are forms of semi-mountable kerb.

Source: RTA (1996).

The following guidance should be considered in regard to the use of barriers in conjunction with kerb:

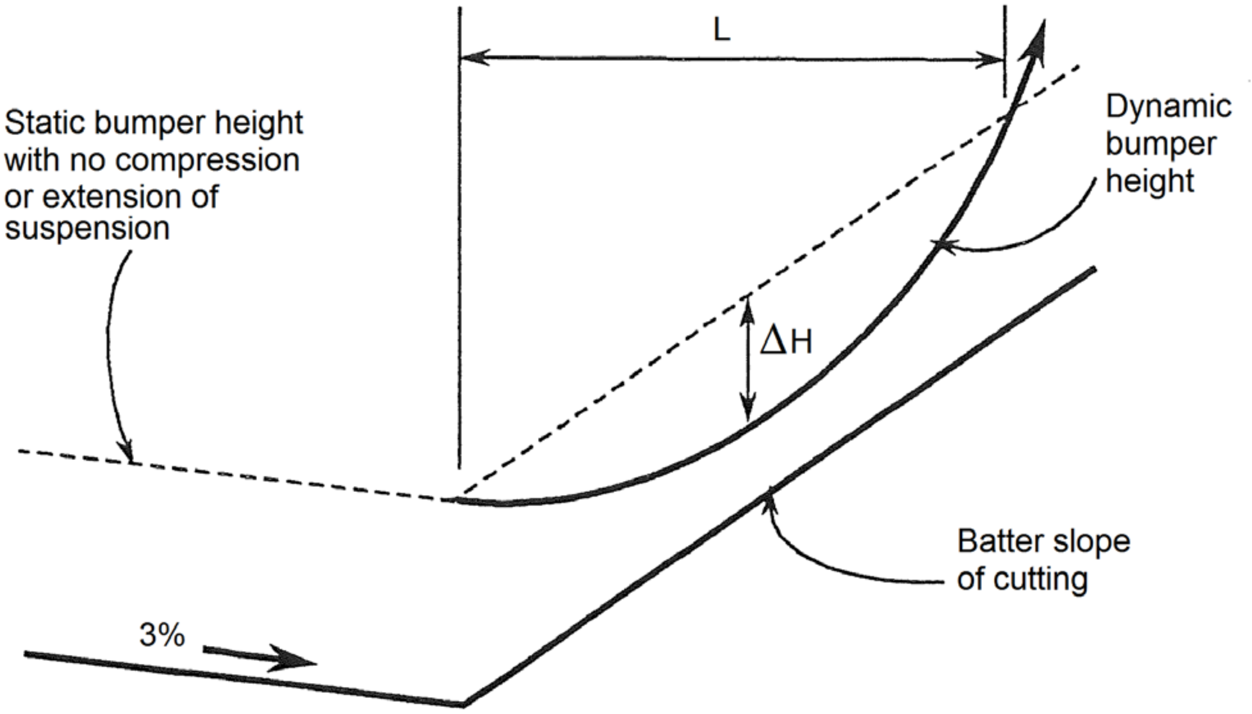
- Kerb should not be located in front of or under semi-rigid or flexible road safety barriers on high-speed roads; a drain located behind the barrier, a shallow gutter immediately in front of the barrier, or subsurface grated drainage system are the preferred drainage solutions. Crash tests have shown that the use of any barrier/kerb combination where high-speed, high-angle impacts are likely should be discouraged. Where there are no feasible alternatives, AASHTO (2006) suggests that designers should consider using a kerb no higher than 100 mm and consider stiffening the barrier to reduce potential deflection.
- Rather than locating a kerb close to the face of a rigid road safety barrier, drainage should be facilitated by the face of the barrier.
- Where a kerb must be used in conjunction with semi-rigid or flexible barrier, as is often the case in urban situations, it is desirable that it is placed either within the distance L1 of the kerb or beyond distance L2 shown in Figure C12 2; however, the latter location may be impracticable in urban situations.

- To ensure satisfactory barrier performance, it is preferred that the barrier is set back no more than the distances shown in Table 6.3. An offset of this magnitude should also minimise nuisance damage to barriers in low-speed urban situations. A semi-mountable kerb is preferable in these situations, and a barrier kerb should preferably only be used in speed zones ≤ 70 km/h.
- In spite of the above guidance, it is sometimes necessary in urban areas where the speed zone is ≤ 80 km/h to place a barrier behind a footpath and this results in the barrier being located a relatively large distance (and perhaps within distance L2) behind the kerb. Furthermore, in placing barriers on these urban roads, consideration should also be given to the possible adverse affect on traffic flow of a long barrier being placed immediately behind the kerb.

C12.4 Vehicle Trajectory Over Cutting Slopes

When a vehicle runs up a cut batter, the momentum of the body on the front suspension causes the bumper height to be significantly lower than the normal bumper height, as shown in Figure C12 3. The reductions in bumper height can be significant enough (e.g. 200 to 300 mm depending on the vehicle type, speed and batter slope) to cause a vehicle to run under a semi-rigid or flexible road safety barrier. A barrier should therefore not be located in the area defined by L in Figure C12 3 and an example of the distances for specific kerb types is shown in Table C12 3. (RTA 1996).

Figure C12 3: An example of bumper height trajectory characteristics on cutting slopes



Source: RTA (1996).

Table C12 3: Bumper trajectory data over cutting slopes

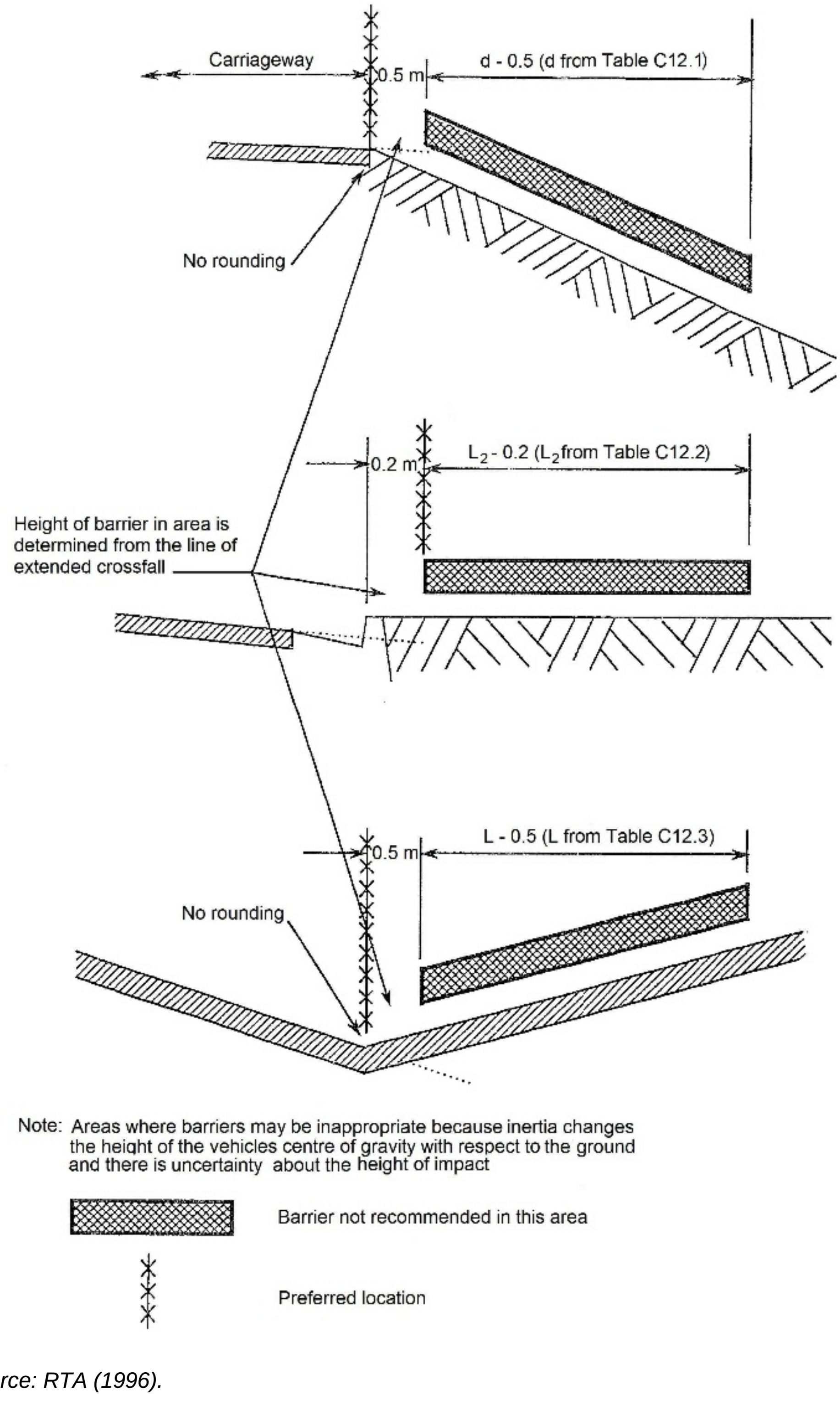
Speed (km/h)	Angle (degrees)	Batter slope of cutting	L (mm)	ΔH (max) (mm)
80	10	2.6:1	1375	285
80	15	2.6:1	1675	320
90	7	8:1	1775	115
90	15	8:1	2450	170
100	7	8:1	1925	120
100	15	8:1	2600	185

Source: RTA (1996).

C12.5 Summary of Limitations on Barrier Location

Figure C12 4 shows an example of the preferred locations of barrier and locations where barriers are not recommended with respect to the behaviour of vehicles passing over embankments, kerbs and cutting slopes.

Figure C12 4: Summary of barrier locations – preferred and not recommended



Note: Areas where barriers may be inappropriate because inertia changes the height of the vehicles centre of gravity with respect to the ground and there is uncertainty about the height of impact

Source: RTA (1996).

Commentary 13

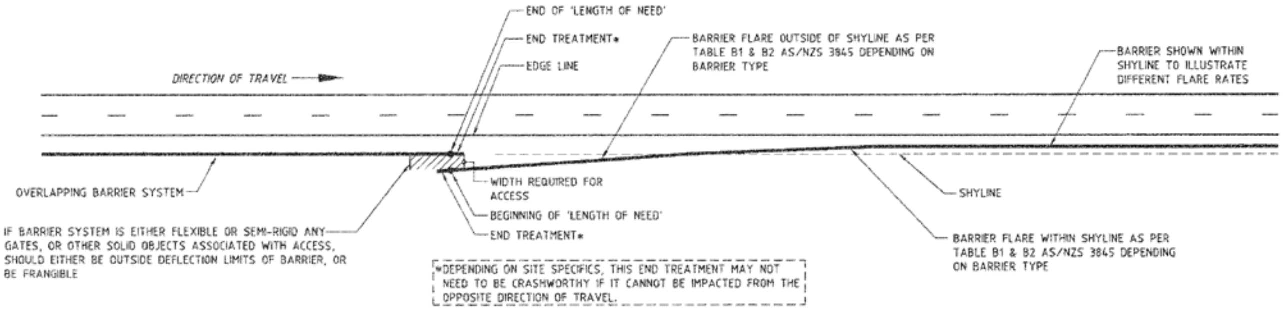
Commonly used crash cushions and impact attenuators use one of two principles to absorb the energy of impacting vehicles at a controlled rate:

- The *kinetic energy principle* whereby the kinetic energy of an impacting vehicle is absorbed by crushable or plastically deformable materials or by other energy absorbers. Some of the energy is also dissipated by the crushing of the front end of the colliding vehicle. This type of system requires a rigid back-up or support to resist the collision force of the vehicle, usually in the form of a ground anchor or other linkage back-up (such as part of the road safety barrier), or both. This type of system is generally referred to as a compression system (AASHTO 2006).
- The *conservation of momentum principle* where the end treatment design involves the transfer of the momentum of an impacting vehicle to an expendable mass (usually sand) located in the vehicle's path. This type of system is generally referred to as an 'inertial road safety barrier' (and may or may not be gating). No rigid back-up is required for this type of system since the energy of the vehicle is not absorbed but transferred to other masses such as sand (AASHTO 2006).

Commentary 14

Relevant road authorities develop layouts for breaks in road safety barrier systems for use where necessary and may have standard drawings for these treatments. The treatment in Figure C14 1 provides an example of an access opening at overlapping barrier systems.

Figure C14 1: An example of barrier access details



Source: Based on MRWA drawing No: 200331 – 174 (MRWA 2007).

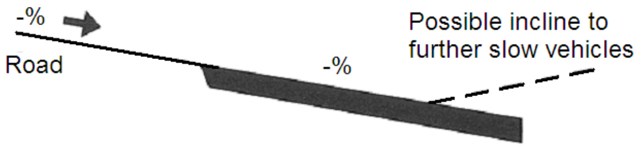
Commentary 15

An escape ramp may be provided on a descending, horizontal or ascending grade as illustrated in Figure C15 1. It requires the use of single sized or uniform graded aggregate to prevent compaction in an arrester bed to increase rolling resistance and, therefore, slow the vehicle. The descending-grade ramps can be rather long because the gravitational effect is not acting to help reduce the speed of the vehicle.

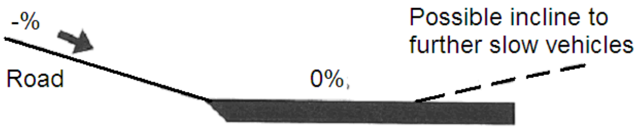
For the horizontal-grade ramp, the effect of the force of gravity is zero and the increase in rolling resistance has to be supplied by an arrester bed composed of single sized or uniform graded aggregate to prevent compaction. This type of ramp will be longer than those using gravitational force acting to stop the vehicle.

The ascending-grade ramp uses both the arresting bed and the effect of gravity, in general reducing the length of ramp necessary to stop the vehicle. The loose material in the arresting bed increases the rolling resistance, as in the other types of ramps, while force of gravity acts downgrade, opposite to the vehicle movement. The loose bedding material also serves to hold the vehicle in place on the ramp grade after it has come to a safe stop. Ascending grade ramps without an arresting bed are not encouraged in areas of moderate to high commercial vehicle usage as heavy vehicles may roll back and jack-knife upon coming to rest.

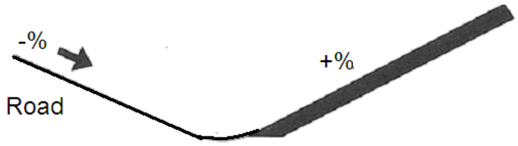
Figure C15 1: Types of vehicle escape ramps



(a) Descending grade



(b) Horizontal grade



(c) Ascending grade

Source: Based on Austroads (2003).

Each one of the ramp types is applicable to a particular situation where an emergency escape ramp is desirable and must be compatible with the location and topography. The most effective escape ramp is an ascending ramp with an arrester bed. On low-volume roads of less than approximately 1000 vehicles per day, clear run-off areas without arrester beds are acceptable.

Austroads’ **Guide to Road Design Part 6: Roadside Design, Safety and Barriers** provides an introduction to roadside design and guidance on roadside safety and the selection and use of road safety barrier systems. Part 6 provides information to enable designers to understand principles that lead to the design of safe roads, identify hazards, undertake a risk assessment process of roadside hazards, establish the need for treatment of hazards and determine the most appropriate treatment to mitigate hazards. A comprehensive design process, guidance and design considerations are provided for the selection of a suitable road safety barrier and for the lateral and longitudinal placement of road safety barrier systems.

Guide to Road Design Part 6

Austroads

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