DEPARTMENT OF INFRASTRUCTURE ENERGY AND RESOURCES

ROAD SAFETY BARRIERS

DESIGN GUIDE

Part A

Transport Infrastructure Branch

Tasmania
Explore the possibilities

PURPOSE

Keywords:

Hazard identification, evaluation, performance standards, crash test, end treatments, types of barrier, design process, longitudinal barriers, end treatments, crash attenuators, transitions, maintenance, temporary safety barrier systems.

The purpose of this guide is to provide guidelines for the identification of the need for a road safety barrier, the selection of an appropriate type of barrier, and the design and location of longitudinal barrier systems.

The guide describes the processes used to identify hazards, test proposed safety barrier systems, evaluate treatment options and to design a road safety barrier system, including the choice of end treatments and transitions.

It outlines a set of guidelines rather than a prescriptive set of standards. Therefore, designers should apply the recommended guidelines in conjunction with their own knowledge, experience and judgement to develop the most appropriate treatment for the issue that they are considering. However, every effort should the made to achieve the objectives of the guidelines whenever it is practically feasible.

CONTENTS

TABLES

FIGURES

1. INTRODUCTION

1.1 General

Roads should be designed and constructed to provide for the safe, convenient, effective and efficient movement of people and goods. However, standards adopted for the design of roads are influenced by terrain, traffic volumes, vehicle types and travel speeds, and must consider the costs the community is prepared to pay. Community costs include initial construction costs, ongoing maintenance costs, user operating costs and costs associated with road crashes. The significant costs associated with crashes are borne by both individual road users and the community as a whole.

It is expected that drivers travelling at speeds appropriate to the conditions and driving with due care will remain on the road and reach their destinations safely. Inevitably there are occasions when vehicles leave the roadway due to factors that may include:

- driver fatigue
- driver error or inattention
- excessive speed
- influence of alcohol or drugs
- road conditions
- mechanical fault
- weather conditions
- unexpected events.

When drivers lose control and leave the road there is a risk of injury and damage due to collisions with unyielding objects (e.g. trees and poles) or non-traversable features (e.g. drains, berms or rough surfaces) that may cause the vehicle to vault (i.e. become airborne), rollover over or stop abruptly. Ideally, the roadside should be free of potentially hazardous features so that errant vehicles can be brought under control safely. However, this is not always practicable for economic, environmental or other reasons, and consideration should then be given to installing safety barriers. The roadside is defined as the area between the outer edge of the shoulder (or kerb) and the right of way boundary. There may be cases, however, where hazards beyond the right of way should be considered.

This publication describes the types of safety barriers available and discusses factors that should be considered in assessing hazards, determining the need for a barrier and selecting an appropriate type of barrier. It also describes the process and considerations involved in designing barriers.

The guidelines outlined are concerned primarily with the identification and treatment of hazards associated with new works, but may also be used to review existing roadsides. Sound application of the guidelines should facilitate the provision of appropriate safety barriers to ensure roadsides incorporate a consistent and economic degree of safety.

Safety barrier guidelines have evolved and continue to evolve in response to new and improved products and changes in the design and mix of vehicles using roads. This guide does not suggest that barriers erected under previous guidelines should necessarily be removed or improved as they are likely to be providing a satisfactory service for road users. Barrier replacement and renewal is a matter for individual road authorities.

Types of barriers and end treatments that are not covered in this guide may be developed. However, they should only be used following careful consideration of critical design features, performance records and crash test results that demonstrate compliance with AS/NZS 3845.

1.2 Principles Governing the Use of Safety Barriers

It is not cost effective, practicable or desirable to erect long continuous safety barriers on all roads. While it is preferable from a road safety perspective to remove roadside hazards, or make them safe through some form of treatment, situations arise where the hazard must be shielded by a safety barrier. However, it is important to understand that safety barriers also constitute a hazard to the occupants of errant vehicles.

A barrier should only be installed when the consequences of vehicle impact with the barrier is 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 must be considered before a decision is taken to install a barrier. These may include improvements to the road (alignment, cross section, pavement surface, delineation) and/or the removal or treatment of hazards. For proposed projects, options for the removal, treatment or shielding of roadside hazards are considered during the planning and design phases of the projects.

The assessment of the merit, or otherwise, of installing a barrier should take into account the overall costs of the alternatives, including all costs associated with anticipated crashes and any other costs likely to be borne by the community. The process includes an assessment of risk and economic analysis to assess the benefit of barrier installations compared with other alternatives. Notwithstanding that there are physical, environmental and economic constraints, the preferred treatments (in order of preference) of roadside hazards are:

- removal
- relocation to reduce the chance of them being hit
- redesign so that they can be safely traversed
- redesign to be frangible or break away, or to otherwise reduce severity
- shield with a safety barrier or crash attenuator
- delineate the hazard if the above alternatives are not appropriate.

1.3 Relationship to Australian Standards and Other Guides

Barriers used in Australia should comply with the requirements of the Australian and New Zealand Standard AS/NZS 3845:1999, “Road safety barrier systems”.

The standard includes:

- issues that have to be addressed when specifying installation of these devices
- erection and maintenance practices necessary to achieve an acceptable level of performance
- the process necessary to assess the nature of repairs to a road safety barrier system, or to a crash attenuator system following a crash
- methods to test road safety barrier and crash attenuator systems.

AS/NZS 3845:1999 also sets out general requirements for road safety barrier systems. It states that, to comply with the standard, road safety barrier systems shall be:

- supported by technical literature and assembly instructions that clearly illustrate the essential mode of operation and prominently show the test level achieved in crash testing that has been carried out in accordance with this Standard
- selected and located in accordance with a recognised design procedure that is professionally applied. This procedure shall take account of risk management techniques that address the community of road users and neighbours, which may be affected by the installation
- erected in accordance with the manufacturer's instructions
- maintained in a manner that reflects the specified requirements
- returned into service following a crash only after professional evaluation and execution of repairs
- fitted with end treatments and interface devices that are appropriate to the system being used.

While AS/NZS 3845:1999 provides substantial information for designers and installers of road safety barriers, it does not provide guidance on the determination of need for a barrier or for the selection, location and detailed design of barrier installations. This design guide provides information necessary to apply the requirements of AS/NZS 3845:1999 to various situations that arise in the road environment, and assists designers to:

- assess the need for a barrier (or alternative treatment)
- select an appropriate type of barrier
- determine the length of barrier required and its alignment.

It is important that relevant manufacturers/distributors manuals and specifications are consulted. In particular, any safety barrier product not covered in AS/NZS 3845:1999 must be installed in accordance with the manufacturer’s requirements.

2. ASSESSING THE NEED FOR A BARRIER

2.1 General

In relation to safety barriers, a hazard is an object, area or condition that can cause serious injury or loss of life for vehicle occupants should a vehicle leave the travelled way and drive into or across the hazard. In assessing the roadside for hazards, a risk management process should be used.

Risk Management is the culture, processes and structures that are directed towards realising potential opportunities whilst managing adverse effects. The risk management process is the systematic application of management policies, procedures and practices to the tasks of communicating, establishing the context, identifying, analysing, evaluating, treating, monitoring and reviewing risk (refer AS/NZS 4360:2004).

The information and techniques presented in this guide provide a means to assess the risks associated with roadside hazards and to identify opportunities to reduce risk through the provision of safety barriers or alternative treatments. The use of quantitative risk analysis, cost benefit techniques and qualitative evaluation, together with sound engineering judgement, should result in a rational approach to the installation of roadside barriers in a manner that will maximise the benefits to the community.

Risk analysis is the systematic use of available information to determine how often specified events may occur and the magnitude of their likely consequences (refer AS/NZS 3845 and AS/NZS 4360). It is based on the philosophy of:

- controlling potential losses by analysing costs associated with loss making situations
- determining the risk and probability of such events occurring
- comparing potential losses with the cost of controlling the potential event.

During the feasibility or concept stage of projects and during program development by road authorities, it is desirable that risk assessments are undertaken to determine whether:

- the risk of a crash at a particular site is such that early action is required to mitigate the risk
- some action could be warranted but there are other sites where the need to take action is greater
- no remedial action can be justified, or such action would have such a low priority that the effective decision is to “do nothing” or provide only minor treatment.

Road authorities undertake such analyses in order to establish priorities across a range of various road improvement projects and to develop the most cost-effective programs for utilising available funds. Proposals to provide safety barriers as discrete projects must be assessed in relation to all other types of project proposals.

2.2 Practical Considerations

The extent of the road system means that there are practical and economic limitations to the treatment of existing hazards along roads. Consequently, road authorities should install safety barriers only where there is a need and there is a demonstrated economic benefit.

2.2.1 Rural Environments

For economical and/or environmental reasons, it is rarely feasible to eliminate all hazards with which errant vehicles may collide. Some hazards may be left unshielded if they have no history of crashes and/or the probability of collisions with them is estimated to be low.

For example, long sections of roadside forest or embankment that do not have a significant number of crashes may be left unshielded where drivers can reasonably be expected to be aware of the road environment or operating conditions and to adjust driving behaviour accordingly. In these circumstances however, an inconsistency such as an unexpectedly sharp curve may require special consideration.

2.2.2 Urban Environments

Urban environments are usually characterised by an extensive range of roadside hazards such as utility poles, trees to beautify the streetscape, traffic signal poles, bus shelters, property fences or facades, and other roadside furniture. Like the rural situation, it is not feasible to remove or shield all of these hazards. However, some of the measures described in Section 2.5.2 are implemented on urban arterial roads where objects are considered to be high risk and treatment is viable.

In urban areas the provision of safety barriers must also take into account the desire lines of pedestrians and their safe passage across roads. Short sections of barriers are sometimes used to protect private property or pedestrians on footpaths or shared paths with respect to possible errant vehicles. Unfortunately, sections of safety barrier shorter than recommended in this guide are often used and create a hazard to road users while not providing the expected level of protection. It is essential to address the cause of the community concern and consider alternative lowest risk options, rather than installing unsafe short sections of barrier that will not perform in the way that they have been designed to perform.

2.3 Assessment Procedure

Figure 2.1 outlines four general steps in the procedure for the treatment of roadside hazards. These hazards may already exist within the roadside, or may be structures or formations proposed as part of a conceptual or detailed road design. The steps comprise:

2.3.1 Identify the hazard

Hazards are identified considering crash history, traffic volumes and speeds, clear zone, road geometry, roadside topography, surface condition, and the expected severity outcome of crashes into the roadside hazard.

An accident history is the strongest indication that a hazardous situation exists at a site and that there is a need for improvement. Consequently, crash records have traditionally been used to establish priorities for treatment under accident blackspot programs.

However, for the design of new roads, and for existing roads that have roadside hazards but no crash record, the hazard identification process shown in Figure 2.2 and a risk management approach is used to determine the priority for improvement. Where individual sites may not have an accident problem but collectively the road feature is known to have a worrying incidence of crashes (e.g. bridge end posts), a 'Mass Action' approach may be taken where sites are grouped for the purpose of hazard identification and evaluation (Austroads, GTEP, Part 4, *Treatment of Crash Locations*, 2004).

2.3.2 Evaluate the treatment options (Quantitative and Qualitative Assessment)

A risk assessment of the hazard and treatment options is undertaken using quantitative measures to determine a benefit cost ratio (refer Section 2.5.3, Appendix A and Austroads GTEP Part 4 – *Treatment of Crash Locations,* 2004). The evaluation also includes qualitative assessment for suitability based on social, environmental and other factors.

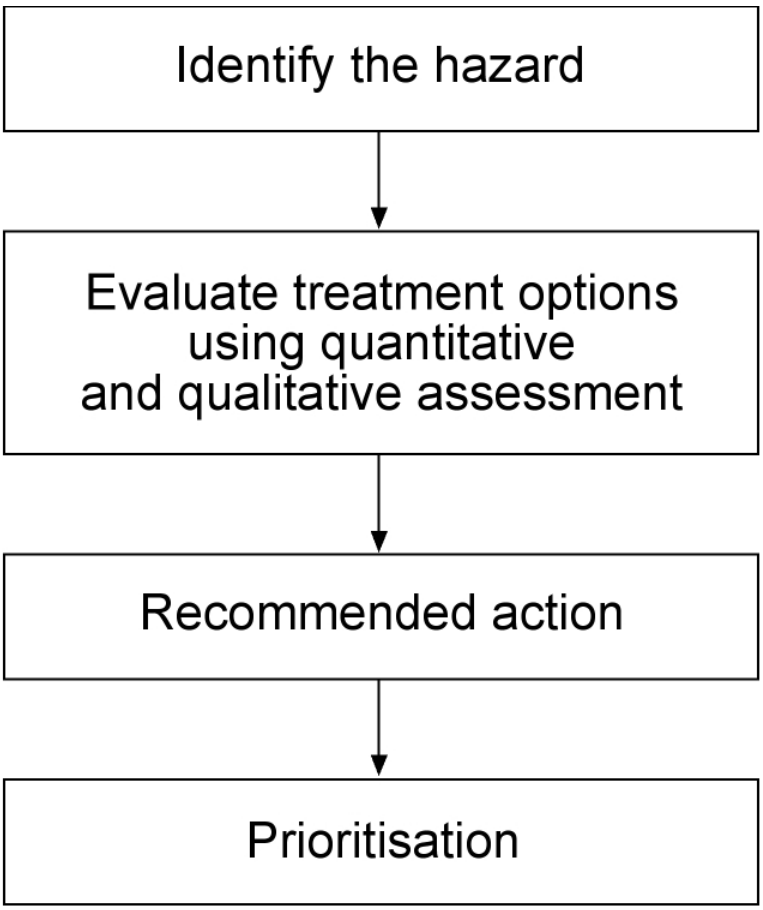
The evaluation process may result in a number of viable treatment options, from which a treatment may be chosen. Some possible treatment options, including those that may be an alternative to the installation of safety barrier, are listed in Section 2.5.2. Because of the number of variables and complexity of the analysis, computer software is usually used for analyses.

2.3.3 Recommended Action

The evaluation will result in a recommended treatment option.

2.3.4 Prioritise Options

Each recommended action for all hazards is ranked according to benefit cost analysis techniques and engineering judgement.



(Source: DMR QLD, 2000)

Figure 2.1 — The Four Step Procedure

2.4 Hazard Identification

2.4.1 General

The identification of roadside hazards is established through the use of crash histories for particular sites or lengths of road (a re-active process) and/or the use of a (pro-active) road safety audit process (refer Austroads Guide to Traffic Engineering Practice, Part 4 – *Treatment of Crash Locations,* 2004 and Austroads *Road Safety Audit*, 2002). The "clear zone" concept is generally applied as a means of identifying roadside hazards for further investigation. (refer section 2.4.7).

2.4.2 Types of Roadside Hazard

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 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 100 mm in diameter
- bridge end posts and piers
- large planters
- hazardous mail boxes or landscape features
- non-breakaway signs
- inappropriate slip bases on signs
- protruding footings (including those for breakaway signs)
- non-traversable driveway headwalls
- non-traversable culvert head walls
- fixed objects in the drain line
- utility poles
- walls or corners of walls
- hydrant bases more than 100 mm high.

It should be noted that while trees less than 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 100 mm in diameter may also be hazardous if they are spaced less than 2.1 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 over 0.6 m deep
- 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 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 a continuous hazard that should be shielded with a median barrier depending on the traffic volume and median width.

2.4.3 Hazard Identification Process

The risk associated with an object is not only dependent on the likelihood of it being hit but also on the severity of a potential collision with the object. A hazard identification process is shown in Figure 2.2. The two possible outcomes from this process are:

- the object has attributes that would make it a hazard to errant vehicles or has a crash history
- the object is low risk as it has low severity attributes and/or is located such that impact is unlikely. No further analysis is required in this case, however monitoring of the crash database and road environs should be undertaken to identify any change in circumstances.

For the purpose of hazard identification, the types of hazard that may be encountered in roadsides can be divided into five broad categories:

- embankments
- fixed roadside objects
- medians (cross median crashes)
- non-traversable open drains
- bodies of water.

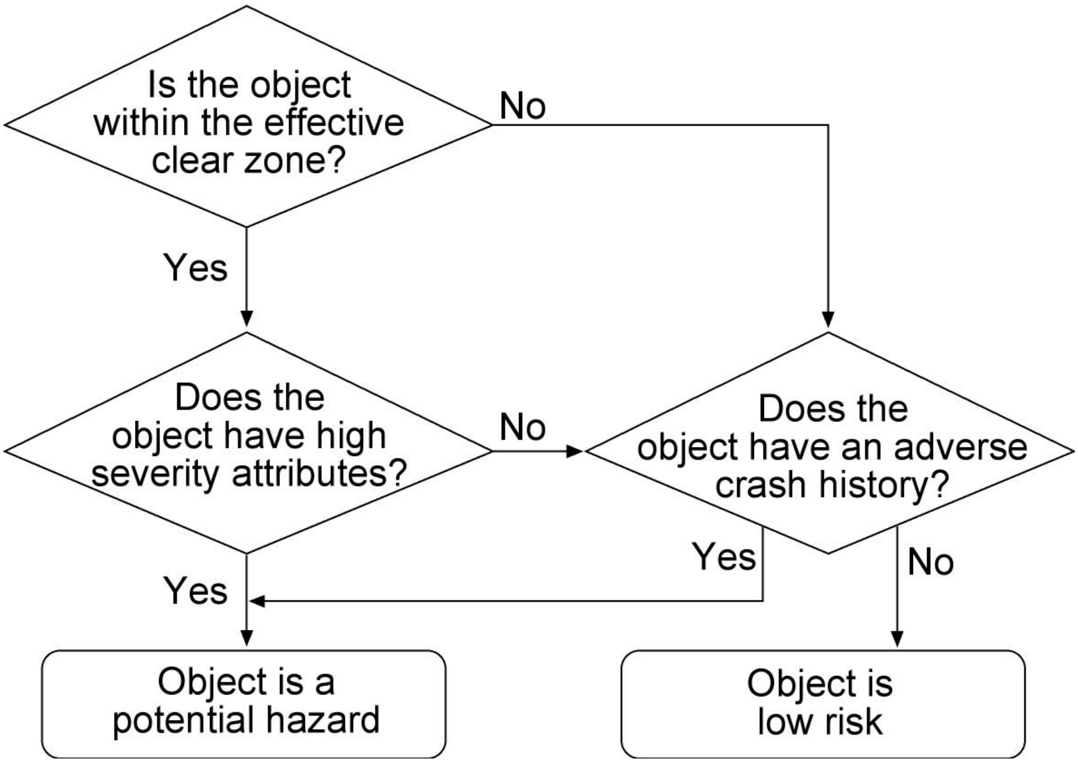
2.4.4 Crash History

The existence of a crash history is the first consideration in identifying an existing roadside hazard. It is normal for crashes within jurisdictions to be systematically monitored in relation to numbers, rates and severity so that particular sites, lengths of road or areas can be assessed. This assessment will provide a basis for the need and priority for treatment.

Crash records are particularly valuable when adequately supplemented by site information. Factors described in Section 2.5.2 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 safety barrier are appropriate at particular sites.

Warrants for the consideration of sites for treatment are often applied in road safety programs and may change over time. As a guide it is generally considered that any roadside object or location that has had at least 3 crashes resulting in a casualty or a vehicle being towed away over a five year period should be considered for remedial treatment. An example of a guide (RTA, 1996) that relates the number and severity of crashes to the need to consider treatment is shown in Appendix B.

Detailed information on investigating crash locations, diagnosing crash problems and developing solutions is contained in Austroads GTEP, Part 4 – *Treatment of Crash Locations* (2004). For midblock locations, the length of the location is 100 m for urban roads and 300 m for rural roads (refer Table 7.1, GTEP Part 4). This is regardless of other factors such as lateral offset (clear zone) and/or traffic volume (DMR QLD, 2000). Remedial treatment does not necessarily involve the provision of safety barrier.



(Source: DMR QLD, 2000)

Figure 2.2 — Hazard Identification Process

2.4.5 Object Severity

The size and rigidity of a fixed object affects the probability and consequence of it being hit, respectively. In this guideline, the term "Severity Index" (SI) is used to assign a weighted severity to an object. It is a measure of the expected severity outcome of an impact with an object or roadside "condition" and is described by values between 0 and 10. A SI of zero anticipates a crash that involves no significant property damage or injury. At the other extreme, a SI of 10 anticipates a crash with a 100% probability of a fatality. Between these extremes, severity indices reflect the relative gravity of other crash outcomes. It is important to note that the SI represents an average severity and not a worst case impact.

A severity index can apply to both natural roadside features and those constructed or formed as part of the road reservation. For example, safety barriers and open drains have a severity index associated with them.

The severity of a crash will vary with the type of vehicle involved, its speed, impact angle and the type of object/condition impacted. Table 2.1 provides severity indices for various speeds and objects/conditions. The selection of a severity index is subjective and local knowledge may be used to adjust the suggested values. More detailed severity indices can be found in AASHTO (1996).

The costs associated with each severity index are determined by road agencies and increase each year. They are used in the economic evaluation of alternative proposals to treat a hazard.

Table 2.1 — Typical Severity Indices for Various Features and Design Speeds

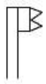
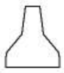
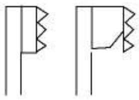
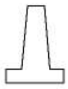
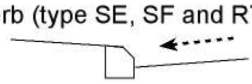
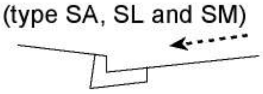
Roadside feature	Design speeds (km/h)		
	≤ 70	**80 – 90**	**≥ 100**
Safety barriers:			
a) Non-rigid systems			
Wire fence 	1.5	2.0	2.5
W beam (G4) 	2.0	2.5	3.0
Tric bloc 	2.0	2.5	3.0
Thrie beam 	2.0	2.5	3.0
b) Rigid systems			
Type F 	2.0	2.5	3.5
Type VCB 	2.0	2.5	3.5
Drains and kerbs:			
Note: Dotted, arrowed lines show the direction of vehicle approach			
Unlined table drain 	2.0	2.5	3.0
	SK 1.0 SB,SC 1.0	2.0 1.5	3.0 2.0
Mountable kerb (type SE, SF and RT) 	0.5	1.0	2.0
Barrier kerb (type SA, SL and SM) 	2.0	2.5	3.5

Table 2.1 — (continued)

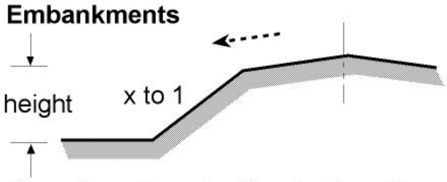
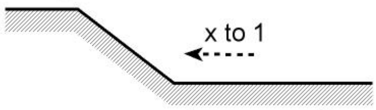
Roadside feature				Design speed (km/h)		
				≤ 70	**80 – 90**	**≥ 100**
Embankments  Smooth, well graded firm batter with no obstacles	**x**	Height (m) lower value	Height (m) upper value			
	1.5	1.0	2.5	2.0 - 5.0	2.5 - 6.0	3.0 - 7.0
	2.0	2.0	4.0	2.0 - 5.0	2.5 - 6.0	3.0 - 7.0
	3.0#	4.5	7.5	2.0 - 5.0	2.5 - 6.0	3.0 - 7.0
	4.0#	10.0	14.0	1.5 - 4.0	2.0 - 5.5	2.5 - 7.0
	5.0#	any		1.0	1.5	2.0
	10.0#	any		0.5	1.0	1.5
# With suitable roundings						
Rough batter or batter with no roundings, or a soft batter.				5.0	6.0	7.0
Near vertical drops (With or without water present)	Water depth (m)	Height of drop (m)				
	≤ 1.0	0 - 6		3.0 - 7.0	3.0 - 7.0	3.5 - 8.0
	2.0	0 - 4		5.5 - 7.5	5.5 - 8.0	6.0 - 8.5
	4.0	0 - 2		6.5 - 8.0	7.0 - 8.5	7.5 - 8.5
	≥ 6.0	All		9.0	9.5	9.5
	Regardless of depth	6 - 10		7.0 - 9.5	7.0 - 9.5	8.0 - 9.5
		> 10		10	10	10
Vertical drops (Locations such as pavement excavations, etc. up to 0.5 m in depth)				3.0	3.5	4.0
Cuttings 						
Smooth, well graded and firm batter	x					
	≤ 1.0			2.5	3.5	4.5
	2.0			2.0	2.5	3.5
	3.0			1.0	2.0	2.5
	≥4.0			0.5	1.5	2.0
Rough batter	x					
	≤ 1.0			4.5	5.5	6.5
	2.0			3.5	5.0	6.5
	≥3.0			3.5	5.0	6.0
(These values to be compared with table drain figures and the largest adopted).						

Table 2.1 — (continued)

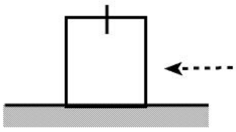
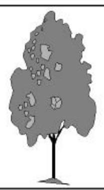
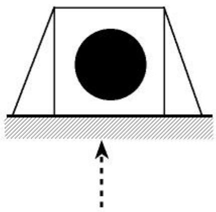
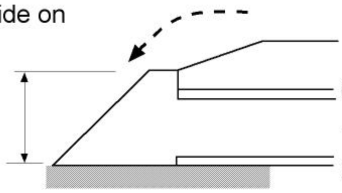
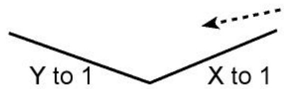
Roadside feature	Design speed (km/h)		
	≤ 70	80 – 90	≥ 100
Non frangible objects Examples Bridge piers, bridge end posts, type “F” end on impact, and similar  Ends of retaining walls Ends of rock cuttings  Rigid bases of frangible posts protruding more than 100 mm above the vehicle trajectory	5.0	6.0	8.0
Posts, poles and trees  100 mm dia. 200 mm dia. 300 mm dia.	1.0 3.5 4.0	1.5 4.5 5.0	2.0 5.5 7.0
Crash attenuators, breakaway terminal treatments	2.5	3.0	3.5
Trailing terminal (If hit by opposing vehicles)	4.5	5.0	6.0
Culverts: End on  ≤ 450 mm dia. ≥ 900 mm dia.	4.0 4.5	5.0 5.5	7.0 7.5
Side on  600 mm 1200 mm 2400 mm	3.5 4.5 5.5	4.0 5.0 6.0	5.0 6.0 6.5

Table 2.1 — (continued)

Roadside feature	Design speed (km/h)		
	≤ 70	80 – 90	≥ 100
“V” drains  Smooth, well graded and firm ground X / ≥ Y Flat / 3 10.0 / 4 5.0 / 5 4.0 / 10 3.0 / Flat	1.0 1.5 2.0 1.5 0.5	1.5 2.0 2.5 2.0 1.0	2.5 3.0 3.0 2.5 2.0
Dish drain  X / ≥ Y Flat / 3 10.0 / 4 5.0 / 5 4.0 / 10 3.0 / Flat Smooth, well graded and firm ground with suitable rounding	0.5 1.0 1.5 1.0 0.0	1.0 1.5 2.0 1.5 0.5	2.0 2.5 2.5 2.0 1.0
“V” or dish drains in rough or soft ground with sharp slopes on “V” drain or inappropriate rounding	2.5	4.0	5.0
Impact oncoming vehicle	7.5	7.5	8.0
Impact stationary vehicle	3.0	3.5	4.0

Notes:

1. Source: RTA, 1996.
2. The severity indices that are given in these tables have been determined by adapting a ‘best estimate’ based on considerations of an ‘average’ departure angle for the errant vehicles.
3. If the situation being considered has two (or more) factors, as outlined above, the case with the worst (highest) severity index is to be adopted.
4. Direction of impact is shown by a dotted arrow.
5. These severity indices are based on an average traffic composition. Where the traffic composition at a particular site falls outside of this mix, then attention is to be given to the possible ramifications. Where there is a higher than average number of trucks, severity indices are to be multiplied by 1.1; for a higher than average number of buses, use a multiplier of 1.2.
6. Where there is an over-representation of heavy vehicles in the traffic stream, the consequences of penetration should be considered. Specifying a Thrie-Beam or a rigid system may be appropriate to reduce the risk of penetration.

2.4.6 Road Geometry

It has been well documented that road geometry can increase the probability of a vehicle leaving the road. Horizontal and vertical curves can influence both the likelihood of a vehicle leaving the roadway and the lateral distance (i.e. offset) it will travel from the traffic lane. When assessing objects located on the outside or inside of curves, or located on downgrades, consideration should be given to the increased number of vehicle encroachments into the roadside and the likely distance that these vehicles might travel. For example, road curvature can increase the probability of encroachment by a factor of up to 4 when the object is on the outside of a right hand curve.

The gradient of a road can also affect the probability of a vehicle leaving the road, although this effect is not as significant as curvature effects. Where objects are located at the bottom of a grade consideration should be given to increasing the clear zone.

Figures A2 and A3 in Appendix A provide an indication of the increased likelihood of vehicle encroachment from the roadway based upon road curvature and longitudinal grade respectively.

2.4.7 Clear Zones

General

For existing roads the provision of a safe roadside preferably 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. It is not generally feasible to provide width adjacent to the carriageway that will allow all errant vehicles to recover. Therefore it is necessary to reach a compromise or level of risk management. The most widely accepted form of risk management tool for roadside hazards is the 'clear zone concept'.

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 possible. Alternatively, hazards within the clear zone should be treated to make them safe or be shielded by a safety barrier.

The clear zone width is dependent on:

- speed
- traffic volumes
- batter slopes
- horizontal geometry.

The 'clear zone' concept originated in the United States of America in the early 60's and has been progressively refined and updated. It was originally developed for unkerbed high-speed rural highways in the USA.

Clear zone widths vary throughout the world depending on land availability and design policy. For a typical high-speed road the clear zone width varies between 4.0 m (France, South Africa) to 10.0 m (Canada, USA). More recent studies have found that the first 4.0-5.0 m provides most of the potential benefit from clear zones (Austroads, 2003).

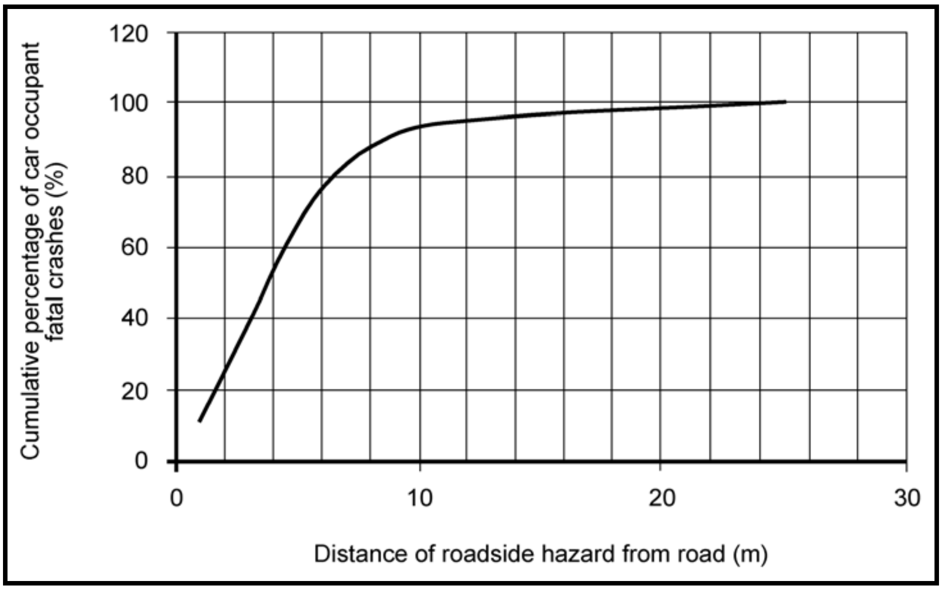
The current Austroads method (refer to Figure 2.4) indicates that the desirable clear zone used for high-volume roads in 100 km/h zones is 9 m wide, measured from the edge of the traffic lane. This value is for straight roads that have batter slopes of no more than 1 on 6. Studies have indicated that a distance of this general magnitude is appropriate. For example, Hutchinson and Kennedy (1966) found that 80–85% of vehicles could recover if the roadside area remained clear for a distance of 9 m on high-speed roads. However, this suggests that, 15–20% of vehicles leaving the road may still be exposed to objects outside of the clear zone.

Furthermore, 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 (refer Figure 2.3). 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 will crash into hazards beyond the clear zone. Designers should appreciate that "clear zone" is a concept and that the computed distances are intended only as a guide, and 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.

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 may 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. 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 (NY, 2003).



(Source: Derived from Kloeden & McLean, 1999)

Figure 2.3 — Distance from Edge of Traffic Lane of Roadside Hazards Causing Car Occupant Fatalities

Austroads method of computing clear zone width

Figure 2.4 provides an indication of appropriate clear zone widths for a straight section of road with recoverable batters. Horizontal curves can influence both the likelihood of a vehicle leaving the roadway and the lateral offset to which it will travel. The probability of encroachment of a vehicle into the roadside on the outside of a right hand curve can increase by a factor of up to four (RTA, 1996).

Designers should therefore give consideration to the increased number of encroachments and the likely distance that those vehicles might travel, particularly where the horizontal geometry is regarded as substandard. Figure 2.5 provides guidance on multiplying factors (F_C) for clear zones on the outside of curves. These factors should be applied to all horizontal curves.

The current Austroads method for determining the appropriate clear zone width is to:

- Determine the desirable clear zone width (CZ) for a straight road from Figure 2.4, based on the 85th percentile speed and the one-way traffic volume.
- Multiply the CZ by an adjustment factor (Fc) from Figure 2.5 to allow for additional width on the outside of horizontal curves. Fc is a function of operating speed and radius of curvature, and varies from 1.0 to 1.9.
- Compute the effective clear zone width (ECZ) by applying the method and formulae in Figure 2.6, ensuring that the value of CZ used in these formulae has been adjusted to account for a horizontal curve where applicable. This calculation allows for moderate to steep batters that affect the distance a vehicle travels down a batter.

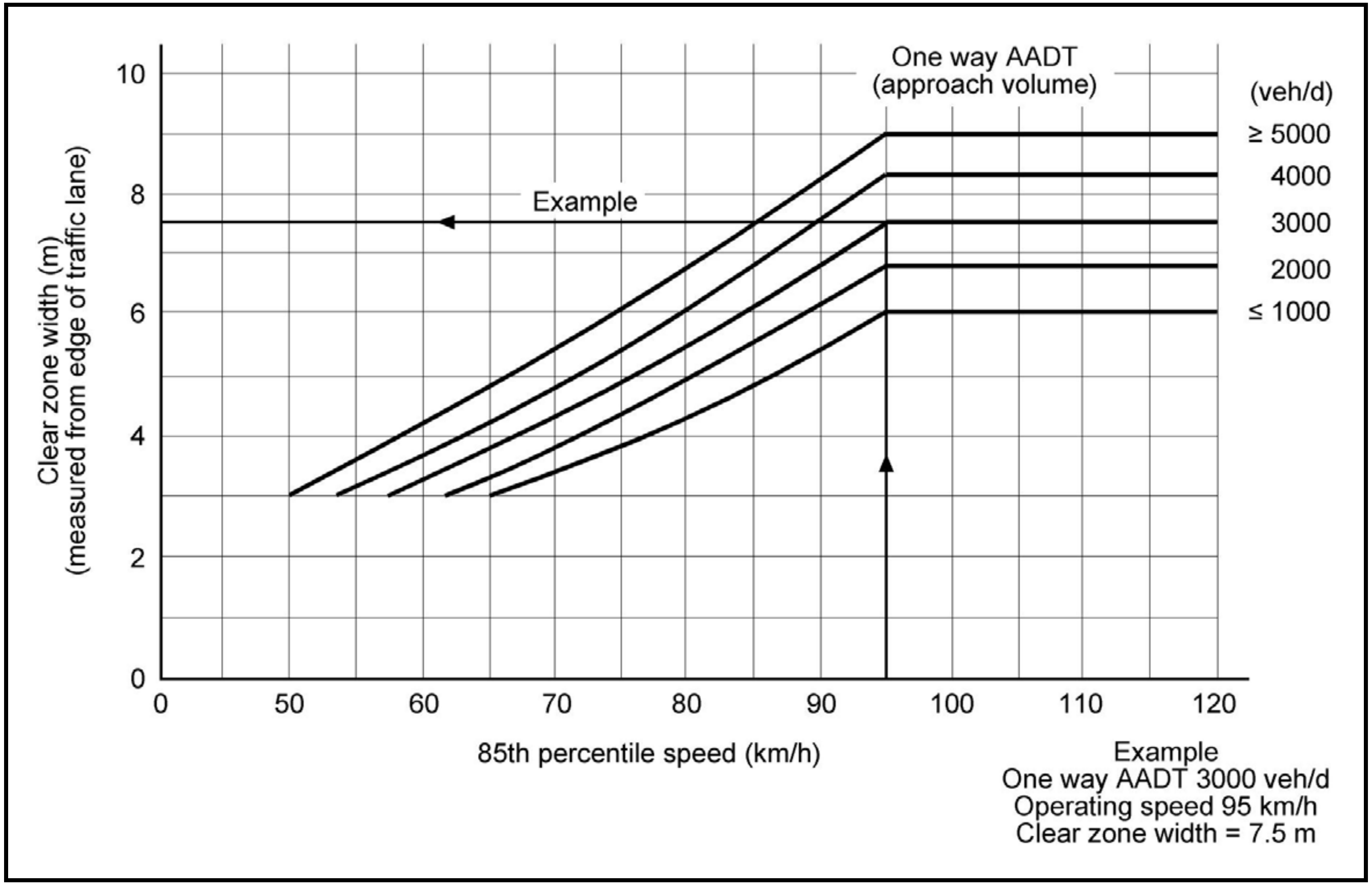
Objects within the resulting effective clear zone width are then considered for removal, treatment or shielding with a barrier.

The consideration of batters in the calculation of effective clear zone width for locations where fill batter slopes are present is dependent on whether the driver of a vehicle that leaves the road is able to regain control of the vehicle. This in turn is dependent on the magnitude of the slope of the batter and the condition of its surface. The driver may recover from the situation by driving through the roadside area or by coming to a stop within it, perhaps in a “run-out” area at the bottom of a fill batter.

The clear zone width (CZ) determined from Figure 2.4 is the width necessary for most drivers to recover control of an errant vehicle and assumes that slopes in the roadside will not have a significant effect on the distance a vehicle travels into the roadside. The effective clear zone width, on the other hand, is the total distance required from the edge of the traffic lane and allows for batter slopes that increase the distance drivers require to regain control and bring the vehicle to a stop. The concept of ECZ is illustrated in Figure 2.6 through several typical cases.

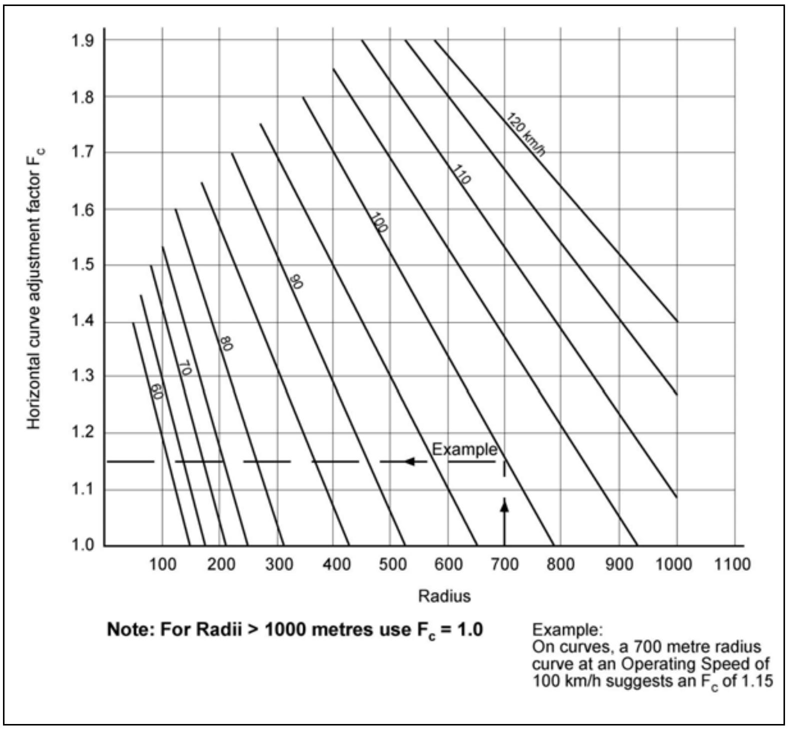
In Case 1, where batter slopes are 1 on 6 or flatter, the batters are considered to be traversable or driveable and will not significantly influence how far an errant vehicle will travel beyond the roadway. It is assumed that these batters are considered to have no effect on the clear zone width to be provided, and therefore the ECZ = CZ.

Case 2 covers the range of batter slopes between those known to be recoverable (1 on 6 to 1 on 4). In these situations drivers are expected to be able to recover and regain control of the vehicle, but the batter slope will influence how far the vehicle travels beyond the roadway. In this case the additional recovery distance required depends on whether the CZ falls with the upper or lower half of the batter slope.



(Source: Austroads, 2002a & 2003)

Figure 2.4— Clear Zone Distance Curves



(Source: Austroads, 2002a and 2003)

Figure 2.5 — Horizontal Curve Adjustment Factors (F_c)

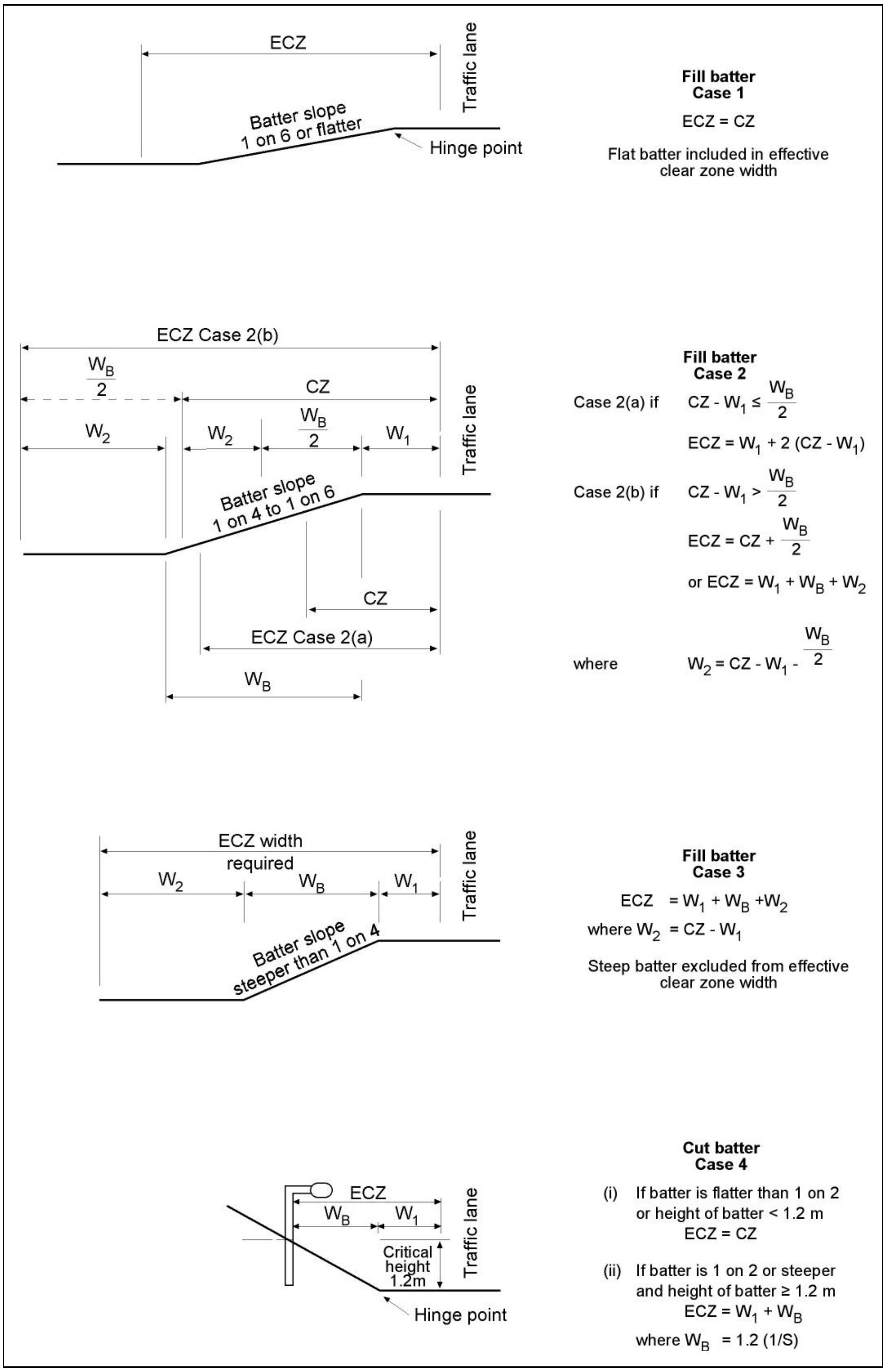
In Case 2(a), where the clear zone (CZ) falls within the top half of the batter, the effective clear zone width is calculated by doubling the batter width of batter within the clear zone distance (CZ) and adding this to the verge and shoulder width. In this case it is assumed that the vehicle will come to rest before it reaches the toe of the batter.

In Case 2(b), where the clear zone (CZ) falls within the bottom half of the batter, the effective clear zone width is calculated by adding half the batter width to the CZ distance. In this case it is assumed that the vehicle would runout into the area beyond the toe of batter (i.e. W_2 in Figure 2.6).

In Case 3, where batter slopes are 1 on 4 or steeper, the batters do not assist recovery at all and an errant vehicle will travel at least to the toe of the batter and probably beyond. Therefore, the widths of these batters are excluded from the calculation of clear zone widths and a significant runout width (W_2) may be required beyond the toe of the batter.

A batter slope of 1 on 6 is desirable where it can reasonably be achieved as it better caters for the different characteristics and performance of heavy commercial vehicles. This may be particularly important on roads that carry relatively high volumes of trucks. Hazards on cut batter slopes of 1 on 2 or steeper generally do not require protection provided that the hazard is located higher than 1.2 m above the toe hinge point. However, the toe of the embankment should be rounded to prevent the front of the vehicle from snagging on the cut face.

For cut batters flatter than 1 on 2, or where the height of the batter is less than 1.2 m, the effect of batter slope can be ignored for the purpose of determining an effective clear zone. That is, the effective clear zone width equals the clear zone width from Figure 2.4, adjusted for road curvature.



Notes:

1. CZ is the clear zone width determined from Figure 2-4 adjusted for horizontal curve where necessary.
2. ECZ is the Effective Clear Zone width.
3. W_1 is the width from edge of through lane to hinge point.
4. W_B is batter width.
5. W_2 is width from toe of batter.
6. S is batter slope (m/m).
7. Provide batter rounding to all batter top and toe hinge points.

Figure 2.6 — Effect of Batter Slope

Austroads *Rural Road Design* (2003) provides guidance on design batter slopes. The desirable and maximum fill batter slopes depend on the type of road (e.g. arterial or local) and the height of fill. The guide reflects that it is often impracticable to flatten relatively high fill embankments due to cost and effects on abutting properties.

The classification of slopes in Austroads *Urban Road Design* (2002a) and Austroads (2003) is generally consistent with the definitions in AASHTO (2002) but apply embankment slope in a different way in the computation of clear zone widths.

The AASHTO Roadside Design Guide defines fill embankment slopes as "Recoverable", "Non-recoverable" or "Critical" (AASHTO, 2002). The definitions of these slopes presume that the slope is traversable, that is, a driver can drive a vehicle over the slope without encountering a hazard. A slope on which a motorist may, to a greater or lesser extent, retain or regain control of a vehicle is considered to be a "recoverable" slope. Slopes flatter than 1 on 4 are generally considered recoverable. A slope on which an errant vehicle will continue to the bottom is considered to be "non-recoverable". Embankment slopes between 1 on 3 and 1 on 4 may be considered traversable but non-recoverable if they are smooth and free of fixed objects. A slope on which most errant vehicles are likely to overturn is called a "Critical" slope. Slopes greater than 1 on 3 are regarded as critical.

The AASHTO (2002) method differs from the Austroads method in that it:

- Takes roadside slopes into consideration in setting the clear zone (CZ). The method provides the clear zone width (as a range) required for various combinations of design speed, design ADT, and batter slopes.
- Road curvature factors are normally only considered where crash histories indicate a need, or a specific site investigation shows a definitive crash potential which could be significantly lessened by increasing the clear zone width, and such increases are cost-effective.

Designers may choose to consider the AASHTO method when considering the appropriate clear zone to be adopted. The gradient of a road can also affect the probability of a vehicle leaving the road, although this effect is not as significant as horizontal curvature effects. Where objects are located at the bottom of a significant grade (4% to 6%) consideration may be given to increasing the clear zone. While no firm guidance can be given regarding the appropriate increase in clear zone width, designers may consider the likely increase in encroachment rate (refer Figure A3, Appendix A), the general background to clear zone widths described previously in this section, and the cost implications of an increased width.

An alternative method of computing clear zones is provided in the AASHTO Roadside Design Guide (2002) and designers may choose to apply this method in assessing the desirable clear zone width.

It should be noted that the clear zone widths were developed on unkerbed roads. In applying the concept to kerbed roads it is assumed that the presence of a kerb does not affect the extent of clear zone required.

In an urban low speed environment it can be difficult to achieve a 3 m clear zone, the minimum indicated in Figure 2.4. Existing hazards are often within the clear zone and can be expensive or impracticable to relocate. Aesthetic and urban design considerations become more predominant and it is the role of the designer and road authority to determine an appropriate compromise. In these situations it may be appropriate to accept a reduced clear zone, perhaps as little as 1 m, to balance the competing community needs. A clear zone of less than 1 m is not desirable. However, where non-frangible objects are located within the clear zone consideration should be given to shielding these hazards with a barrier. For greenfield sites in a low speed environment a clear zone of 3 m to 4 m (i.e. for 50 to 60 km/h speed environment) should be considered and achieved where practicable. It is also important to recognise that at lower speeds the severity of impact with a safety barrier may be similar to an impact with a fixed object.

2.5 Evaluation and Selection of Options

2.5.1 General

This section briefly describes the types of treatment options and a procedure for the evaluation and prioritisation of options. Evaluation should consider both quantitative and qualitative aspects.

Quantitative evaluation generally involves a quantitative assessment of risk and an economic analysis of options, taking into account the probability of vehicles encroaching into the roadside, the likely severity of crashes should an encroachment occur, and the social costs associated with encroachments. In such analyses roadside hazards and safety barriers are assigned a severity index that determines the likely cost of encroachments. Qualitative evaluation includes environmental and engineering considerations and, in many situations, a subjective assessment of risk.

2.5.2 Treatment Options

A decision to install a safety barrier should be taken only after all alternative options have been investigated. This should include consideration of the following factors.

Likelihood of Encroachments into the roadside

Drivers run off the road for many reasons, including those described below. Provided that it is practically and economically feasible, it is preferred that measures are taken to prevent vehicles from leaving the road as well as protecting those drivers who leave the road from crashing into hazards.

The likelihood that a vehicle will leave the road may depend on factors such as:

- Road geometry, including sight distance. Vehicles are more likely to leave the road at curves that have small radii or inadequate pavement crossfall and 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 from 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.
- 'Driver pressure'. Drivers are more likely to make errors when traffic conditions and road geometry interact to limit their ability to select vehicle speed and path independently of other road users. Driver pressure is a qualitative measure of the combined effects of the preceding factors.
- 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 taking the following measures.

Keeping Vehicles on the Road

Adoption of appropriate geometric design standards and road maintenance standards is the basic safety requirement, but there are some particular actions that can be taken to assist in minimising the number of errant vehicles. These include:

- Delineation of alignment; this may involve provision of guide posts, edge lining, hazard markers, or planting of shrubs or trees at strategic locations (provided that they are not a hazard).
- Provision of consistent warning signs and advisory speed signs and their subsequent maintenance.
- Elimination of roadside distractions, particularly at locations where driver decisions are required.
- Avoidance of misleading cues, e.g. gaps in trees, or 'straight ahead' service pole lines when road curves away.
- Provision of tactile edge lines to minimise the risk of running off the road as a result of driver fatigue or driver inattention.

Reducing the Consequences of Encroachment

Research 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.

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
- adequate clearances to structures
- provision of underground utility services.

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

2.5.3 Evaluation

An evaluation of a particular roadside safety issue may consider a range of options, including provision of a safety barrier. Each option will have a different economic performance and the evaluation will determine which treatments are viable. In the absence of environmental factors, the most cost-effective treatment (or combination of treatments) will usually be adopted.

Quantitative Evaluation

Quantitative evaluation uses numerical values for both the likelihood of a run-off road crash occurring and the consequences of the crash. 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). For run-off road crashes this may involve the use of encroachment factors and severity indices (refer Appendix A) that are used with other information to quantify the events.

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. However, simply having a benefit/cost ratio greater than one may not be justification for the construction of a roadside safety treatment. Each project must compete with others for limited safety funds. Austroads (2004) provides information on justifying expenditure on road safety projects and the economic appraisal of projects and also provides estimated crash reduction factors for various treatments. It should also be noted that software such as the Department of Main Roads' Queensland "Roadside Incident Severity Calculator" (RISC) automates this process, supplying benefit to cost ratios for each treatment option (as does the USA Roadside Safety Analysis Program, RSAP).

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).

Austroads *Benefit Cost Analysis Manual* (Austroads, 1996) provides guidance on the theory of calculating Benefit Cost Ratios. The following is a brief summary of this theory and its application to this situation:

The Benefit Cost Ratio is defined as the Net Present Benefit (NPB) divided by the Net Present Cost (NPC):

BCR = NPB / NPC

The NPC is defined as the cost of implementation (discounted if not undertaken in the first year). The NPB is defined as the total value of benefits due to crash reduction over a defined period based on an economic discount rate.

NPB = (discount factor) x B

The discount factor varies for different values of rate and period, and B is the value of annual benefits (e.g. annual reduction in road crash cost).

Factors required for the determination of a benefit cost ratio are:

- cost savings in crashes prevented or reduced in severity (reduction in road crash cost)
- cost of implementing the treatment
- cost of maintaining the treatment
- cost of repairing the treatment if hit
- life of the treatment
- length of analysis period
- discount rate.

The BCRs determined for roadside hazard or barrier treatments can then be prioritised within the various programs of jurisdictions along with other types of road safety and road projects.

Quantitative analysis can be complex and computer software packages can be used to assist in comparing options. For example, the Road Safety Risk Manager (RSRM) computer software, developed by ARRB Transport Research Ltd in association with Austroads, may be used for assessing the risk associated with a range of road hazards and treatments, including those related to safety barriers (ARRB, 2005). RSRM can also be used to prioritise possible treatments on the basis of a treatment risk reduction to cost ratio, but does not calculate BCRs. Other software such as the Department of Main Roads Queensland Roadside Incident Severity Calculator (RISC program) has also been developed to perform the quantitative analysis and computes benefit to cost ratios for each treatment option.

Road safety practitioners may also refer to USA Roadside Safety Analysis Program (RSAP) that also computes BCRs, [TRB web site (http://www4.trb.org/trb/crp.nsf/0/898c0a909da3cefa8525674800561af7?OpenDocument)];

Qualitative Evaluation

Before a treatment option is selected for prioritisation and implementation, its suitability in terms of the following issues should be considered:

(i) Environmental considerations that 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.

(ii) Engineering considerations that include:

- traffic growth
- pedestrian and cyclist traffic (including children)
- vehicle mix including motorcyclists
- crash history
- other geometric influences
- social justice/equity
- school bus route
- freight route.

For example, sites that have a crash history need to be evaluated such that an appropriate priority for treatment can be assigned. Another example is school bus routes that normally 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).

2.5.4 Prioritisation of Selected Treatment Options for All Hazards

The following procedure is recommended for ranking selected treatment options:

- select the optimal treatment option for each hazard identified, using quantitative and qualitative evaluation
- list and rank the selected treatment options for all hazards identified, according to benefit cost ratios and environmental and engineering factors
- treat hazards with the highest ranking, as funds become available.

Austroads (1996) provides some detail on evaluating and prioritising treatment options. Although the Road Safety Risk Manager (developed by ARRB Group in association with Austroads) does not provide BCRs or account for all possible scenarios, it is a useful tool for providing an initial ranking of potential projects for the treatment of hazards.

2.6 Assessment of Specific Hazard Types

2.6.1 Embankment Assessment

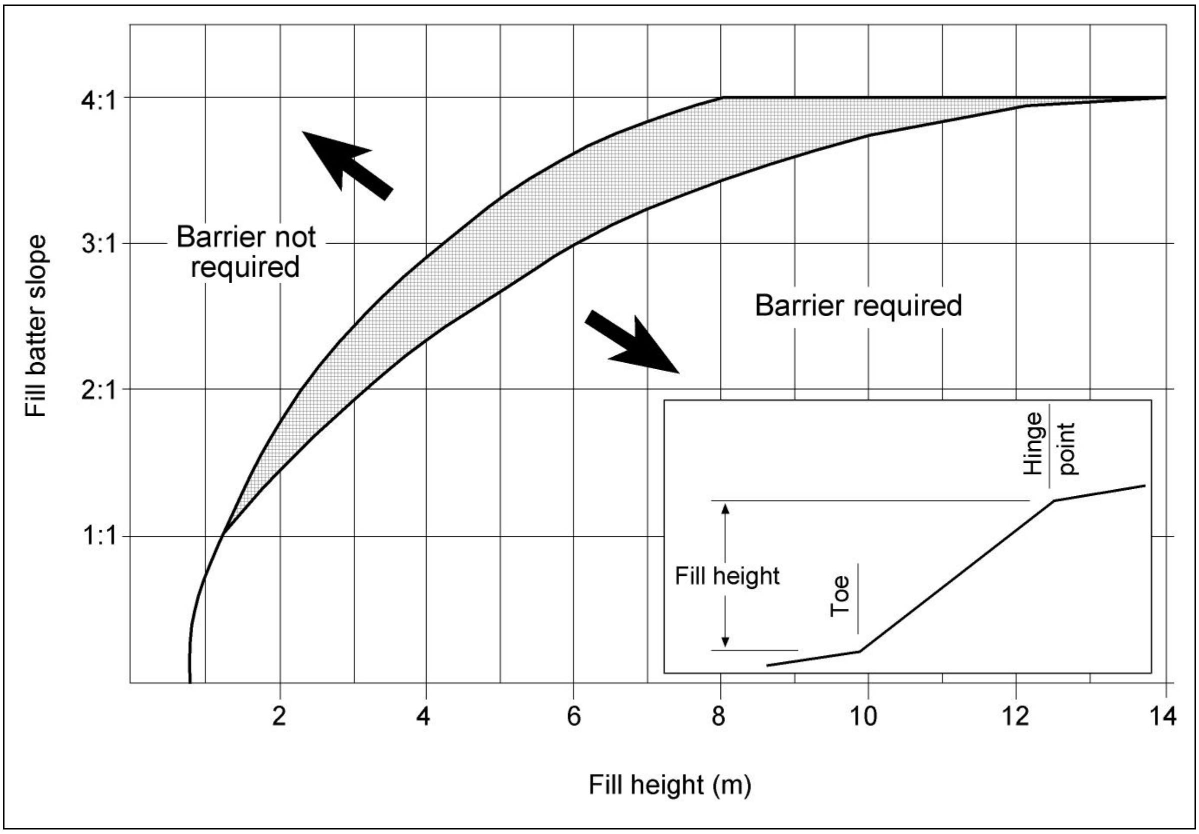
Warrants for the use of safety barriers to shield embankments have largely been based on the relative accident severity of an errant vehicle striking a W-Beam barrier compared to running down the embankment and possibly rolling. It has been shown (Ajluni, 1989) that:

- about 25% of all off-road crashes result in rollover

- the likelihood of rollover increases with embankment steepness, height and drain depth
- for passenger cars, the frequency of rollover decreases as vehicle weight increases
- in most (50 to 80%) rollover crashes, the vehicles skidded out of control at a large sideslip angle prior to overturning
- the fatality rate for occupants of rollover vehicles is approximately twice that for occupants of vehicles in non-rollover impacts.

This emphasises the desirability of batters being constructed to an acceptable slope and free of features that would prevent an errant driver from regaining control of a vehicle. If this cannot be achieved, consideration should be given to shielding the embankment with a safety barrier.

Following improvements in W-Beam barrier performance and a better appreciation of vehicle rollover on fill batters, the warrants shown in Figure 2.7 were developed. This graph provides a quick, general assessment as to whether a barrier (W-Beam) is warranted to shield an embankment. It is based only on the relative severity of driving over embankments of various heights and slopes compared to the severity of crashing into a W-Beam barrier. However, because of the number of variable factors involved in the likely severity of collisions involving embankments, the different characteristics of other types of barrier, and the need for a sound basis on which to prioritise works, road authorities often undertake a more detailed assessment.



Notes:
1. Figure applies only to W-Beam installations.
2. Barrier is required for shaded area unless a detailed assessment proves otherwise.
3. Assumes that batter is traversable and clear of hazards.
4. Source Austroads (2003).

Figure 2.7 — Warrants for Barrier on Embankments

Figure 2.8 shows a more detailed process for assessing the treatment of embankments, for which there are five possible outcomes. The quantitative economic analysis referred to in the figure is preferably undertaken using software (refer section 2.5.3).

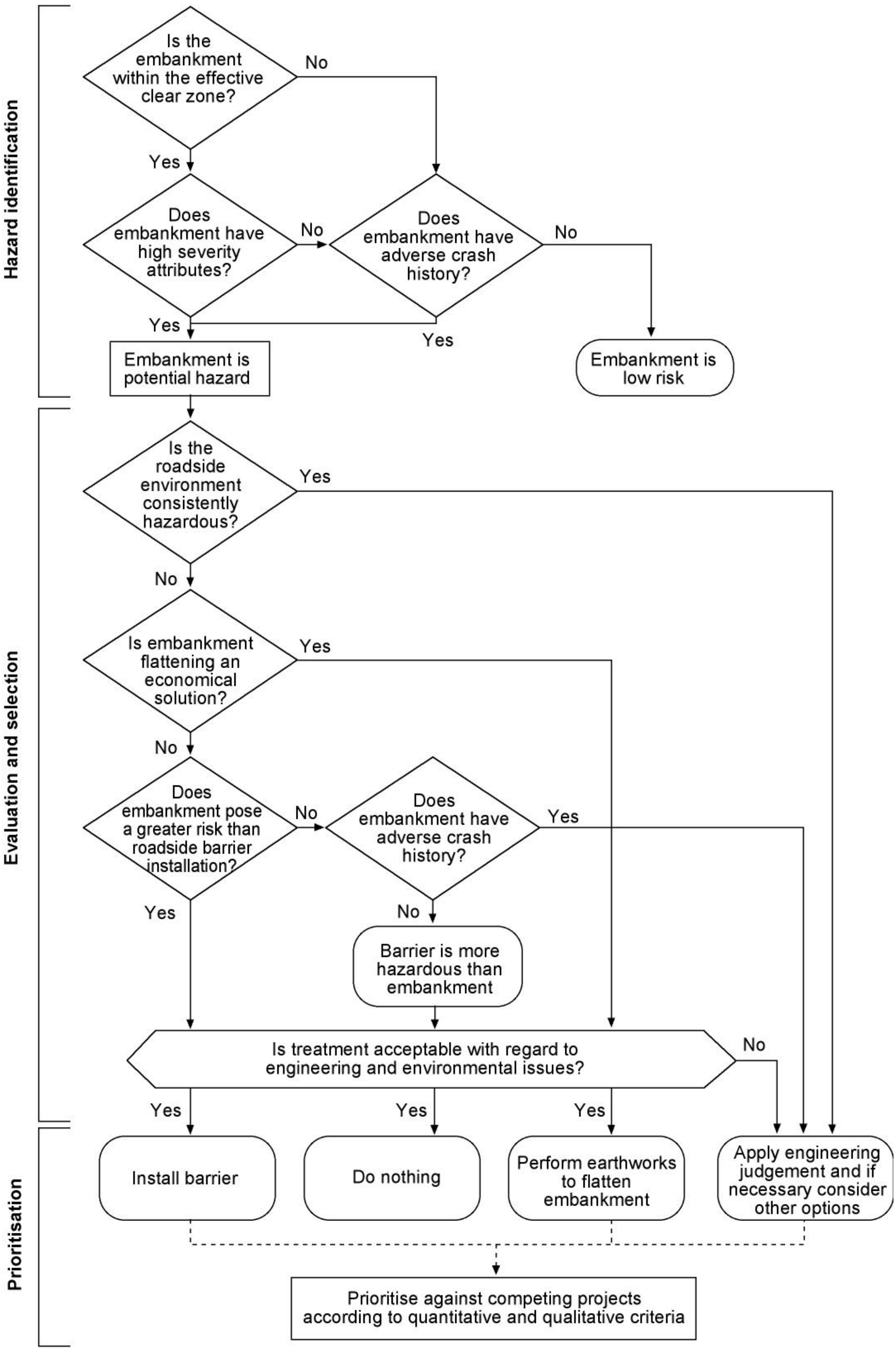
Application of the process will lead to the following possible conclusions:

1. *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. However, monitoring of the crash database and road environs should be undertaken to identify any change in circumstances over time.

> Note: 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.

2. *Flatten embankment*: Given that the installation of a roadside 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.

3. *Embankment is more hazardous than roadside barrier:* Installation of roadside barrier or some other type of treatment is recommended.



(Source: DMR QLD, 2000)

Figure 2.8 — Embankment Assessment Process

4. *Roadside barrier is more hazardous than embankment*: The installation of a roadside barrier is considered to be more hazardous than the untreated embankment. Installation of roadside barrier is not recommended.

5. *Apply engineering judgement and consider other options*: The installation of a roadside barrier may not be recommended, however if required a more detailed assessment may be undertaken and may yield other suitable treatment options (refer Section 2.5.2).

Guidance for assessing embankments in accordance with the process in Figure 2.8 comprises the following steps.

1. Does the embankment have high severity attributes?

Research indicates that 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* – that are parallel to the flow of traffic are described and categorised in subsection 2.4.7. Batter slopes between 1 on 4 and 1 on 3 are traversable but too steep for a driver to recover, and a slope of greater than 1 on 3 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 no greater than 1 on 4 or flatter should be provided wherever possible, 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. However, in order to cater for the different characteristics and performance of heavy commercial vehicles, embankment slopes of 1 on 6 or flatter are desirable where this can reasonably be achieved, particularly where truck volumes are high.

2. Does the embankment have an adverse crash history?

As discussed in Section 2.4.4, it is recommended that any roadside object or location that has at least 3 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.

3. 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 barrier may mean that the installation of 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 safety barrier is not justified:

- ensure that 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 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 safety barrier may be justified.

4. Is embankment flattening an economical solution?

A preferred option to the installation of safety barrier is slope flattening to 1 on 4 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 safety barrier, may be undertaken. This should include the costs associated with crashes, maintenance and installation for each option.

5. Does the embankment pose a greater risk than safety barrier installation?

This involves a comparison of the risks associated with retaining an unshielded embankment with those relating to roadside 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 barrier is justified.

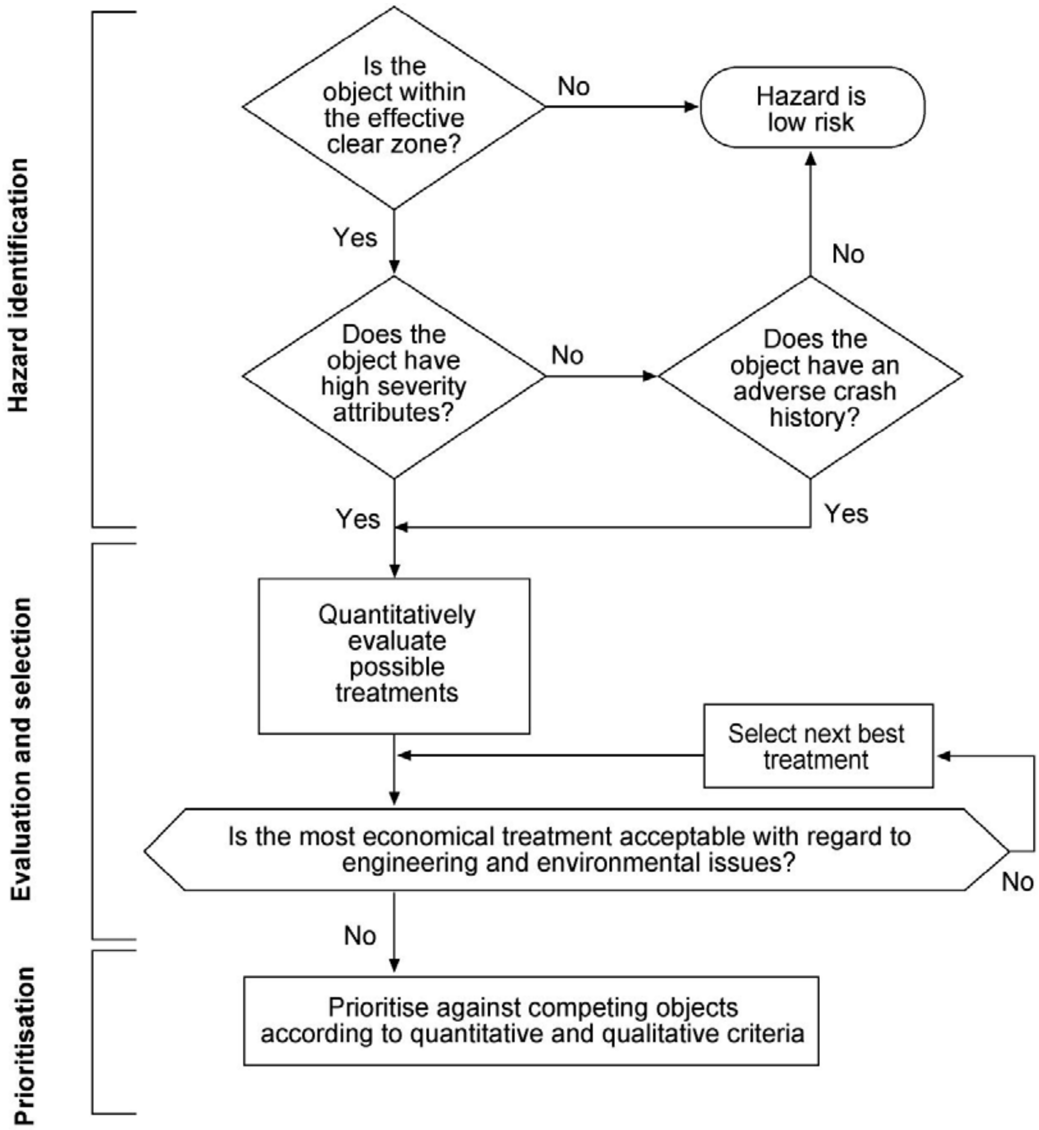
2.6.2 *Fixed Objects Assessment*

Fixed objects within the clear zone constitute hazards and the process in Figure 2.9 is applied for assessing the treatment of these roadside objects. Not all fixed objects will be hazards (e.g. retaining walls). The two primary factors are the probability of the object being struck and the severity of a crash should a vehicle collide with the object. Alternative options to installing safety barrier (refer section 2.5.2) should always be considered as part of the assessment.

The process involves the following considerations:

1. *Is the object within the Clear Zone?*

Section 2.4.7 is used to establish whether the fixed object is within the clear zone and should be considered for treatment.



(Source: DMR QLD, 2000)

Figure 2.9 — Rigid Object Assessment Process

2. *Does the object have high severity attributes?*

Computer software for safety analysis, as used by DMR Qld, usually assigns a weighted severity to roadside objects, including safety barrier, in the form of a 'severity index'. The severity index (refer 2.4.5) ranges from 1 to 10, each level having an estimated crash cost (refer to Appendix A). Typical severity indices are shown in Table 2.1. The following objects are not considered to be fixed objects:

- sign support posts less than 65 mm nominal bore
- slip base poles and frangible posts
- tubular thin walled traffic signal posts (RHS-Rectangular Hollow Section, not included)
- objects behind the "length of need" sections of a safety barrier, provided they are behind the deflection area of the barrier
- wooden objects or mature trees of less than 100 mm diameter at their base.

Examples of high severity objects (in a 100 km/h speed environment) are:

- trees, timber posts or poles greater than 100 mm diameter at the base
- traffic signal posts
- steel sign support posts greater than 65 mm nominal bore (CHS-Circular Hollow Section)
- objects behind the leading and trailing terminals of guard rail
- non-traversable culvert head walls
- open drains (depending upon drain profile and depth of water in the drain, if applicable)
- bridge ends and piers
- ends of retaining walls
- rock cuttings.

This is not an exhaustive list of high severity objects. During a field survey or safety audit any object may be defined as "high severity" if survey staff, using experience and judgement, consider it to have attributes that make it so.

3. *Quantitative Evaluation*

As described above, quantitative evaluation involves the comparison of Benefit Cost Ratios for various treatment options that may be available. For example, in the case of a culvert passing beneath the road an economic comparison can be made between a number of options including:

- leaving an end wall on a culvert as it is and improving delineation (e.g. roads with low AADT or minor classification);
- extending the culvert end wall to a location beyond the clear zone
- redesigning the culvert end wall to reduce its severity
- installing bar grates to make the ends of larger culverts driveable
- installing safety barrier.

Once a roadside object is identified as a potential hazard (i.e. it is within the clear zone determined using the guidance in section 2.4.7, and is deemed to have a higher severity than a barrier), the risk can be analysed. A modelling method can then be used for evaluation. The method used usually calculates:

- a roadside encroachment frequency that is a function of a base encroachment rate, AADT, and factors for curvature, gradient and (at discretion of the analyst) road users
- an object collision frequency for traffic approaching from all directions from which the object could be struck, as a function of the encroachment frequency and the attributes of the object
- annual crash costs based on the estimated number of impacts per year and the unit cost related to the severity index for the object.

The crash costs so determined, and similar computations for treatment options including safety barrier, can be used as the basis for an economic analysis. The modelling process as used by DMR Qld is further described in Appendix A.

2.6.3 Median Barrier Assessment

General

Median safety barriers may be provided where:

- hazardous objects or conditions exist within the median
- there is an unacceptable risk of vehicles crossing the median and crashing into other vehicles on the opposing carriageway.

Median barriers are often provided on:

- high-speed access controlled divided roads that have a speed limit of 90 km/h or more, and where median width or condition requires their installation
- on urban divided roads where a critical slope (greater than 1 on 3) or a particularly hazardous object exists within the median.

As with all barrier installations, a median barrier should only be installed if the consequences of striking the barrier are expected to be less severe than a resulting collision should no barrier be provided, and the hazard cannot be removed, relocated or redesigned.

Hazardous Objects or Conditions

Median barriers may be warranted to protect vehicles from isolated fixed objects located within the median, such as bridge piers or sign supports. Hazards in the medians of freeways and high-speed duplicated highways will normally require shielding whereas those in the medians of lower speed urban or rural roads should be the subject of a risk assessment.

Cross-Median Risk

Various guidelines have been developed in Australasia (e.g. VicRoads) and overseas (e.g. Caltrans in California) for the provision of median barriers on high-speed divided roads.

Figure 2.10 is the guideline provided in AASHTO (2002) for the provision of median barriers on high speed, controlled access roadways that have relatively flat, traversable medians. These criteria are based on limited analysis of median crossover crashes and research studies and are suggested for use where more current or site specific data is not available.

Figure 2.10 indicates that a median barrier is optional above a 10 m median width and is not normally considered above a 15 m width. This may be based on early research that indicated that about 80% of vehicles could recover in this distance (refer section 2.4.7). However, the preferred approach is that a risk analysis is undertaken for proposed new roadworks and for existing roads.

For freeways with relatively flat traversable medians, research (Caltrans, 2003) and various guidelines suggest that:

- when the AADT is less than 20,000 vpd the probability of an out-of-control vehicle crossing the median and colliding with an opposing vehicle is low
- when the median width is more than 23 m the probability of an out-of-control vehicle reaching the opposing lanes is low
- with any AADT or median width, barriers should be considered if there has been a high rate of out-of-control cross median crashes involving opposing vehicles
- a rate based on 3 crashes in 5 years, or 0.31 cross median crashes per kilometre per year of any severity, or 0.073 fatal cross-median crashes per kilometre per year, involving opposing vehicles justifies analysis to determine the advisability of a barrier
- where less than 5 years of accident data exists and the rate criteria is met, further analysis should be conducted to determine the advisability of a barrier
- median barriers should be provided on new construction whenever it is anticipated that they will be justified within five years after construction.

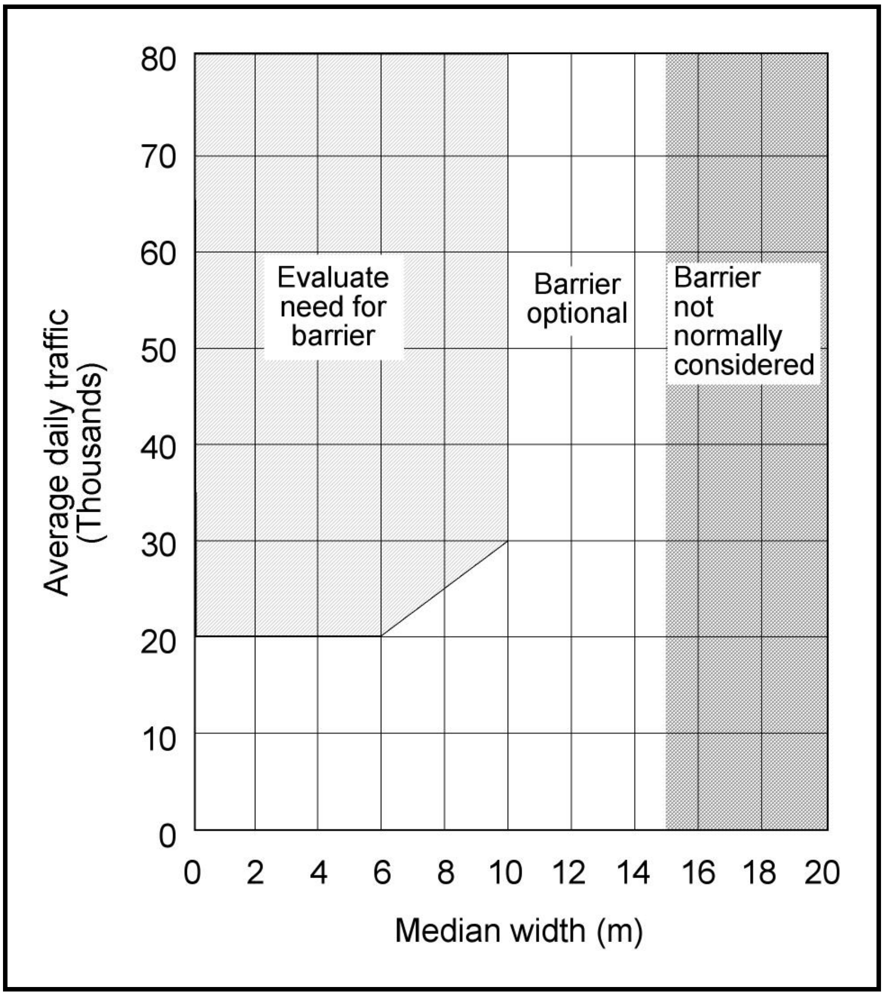
A cross-median crash is strictly defined as one in which an out-of-control vehicle crosses the median of a 4 or more lane road and strikes, or is struck by, a vehicle from the opposite direction. It is considered that these guidelines could also be applied to high-speed rural divided highways.

The above guidance provides only a general appreciation. Designers should always consider all relevant risk factors that relate to the likelihood of vehicles leaving the road, the associated consequences, and undertake a thorough evaluation (refer Section 2.5).

Median widths on typical divided urban arterial roads are relatively narrow and cross median access is usually provided at frequent intervals. When a barrier is installed on these roads to protect against vehicle rollover because of carriageway level differences, cross median crashes or collisions with fixed objects, care must be taken to ensure that the safest possible terminal arrangements are provided.

For non-freeway roads it is essential that consideration is given to the number of intersections, accident history, alignment, driveways, gradient, and sight distance requirements, as well as traffic volumes and median width.

If the median is wide enough and flat enough to accommodate the deflections of flexible or semi-rigid barriers, the use of these barriers may be preferred because of their lower impact severity. For medians where barrier deflection poses an unacceptable risk to opposing vehicles, a rigid barrier is normally used.



Note: Average daily traffic is based on a 5 year projection. Median width is the distance between the edges of the through traffic lanes that are adjacent to the median.

(Source: AASHTO 2002)

Figure 2.10 — A Median Barrier Guideline for High-Speed Roadways

2.6.4 Drainage Channel and Back Slope Assessment

A drainage channel is defined as an open drain usually parallel to the highway and within the limits of the highway right of way. Open drains are present on the majority of rural roadsides and may also exist on urban highways and freeways. Their primary function is to collect and carry the surface water away from the roadway and they are designed to accommodate run-off from storms with minimal highway flooding or damage. Deep 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 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, rounded drains with bottom widths 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 may encounter the following hazards:

- *Drain front slope*. If the front slope is 1:4 or steeper, the majority of vehicles entering the drain will be unable to stop and can be expected to reach the bottom.
- *Drain bottom.* Abrupt slope changes can result in errant vehicles impacting the bottom of the drain.
- *Drain back slope*. Vehicles travelling through the drain bottom or becoming airborne from the front slope can impact the back slope.
- *Structures across drains*. Culverts are often placed within longitudinal drains and if not provided with a trafficable end treatment they may constitute a hazard for errant vehicles travelling through the drain. The same applies to culverts that carry water under roads and intersect with longitudinal open drains.
- *Deep water.* Water deeper than 0.3 m to 0.6 m may cause vehicle occupants to drown (refer 2.6.6).

'Back slope' and 'front slope' are shown in Figures 2.11 and 2.12.

Figures 2.11 and 2.12 present the preferred design for abrupt and gradual change slopes, respectively. Drain cross sections that fall within the shaded region of each of the figures are considered to be traversable. These preferred drain designs are not considered hazardous and need not be constructed at or beyond the clear zone distance.

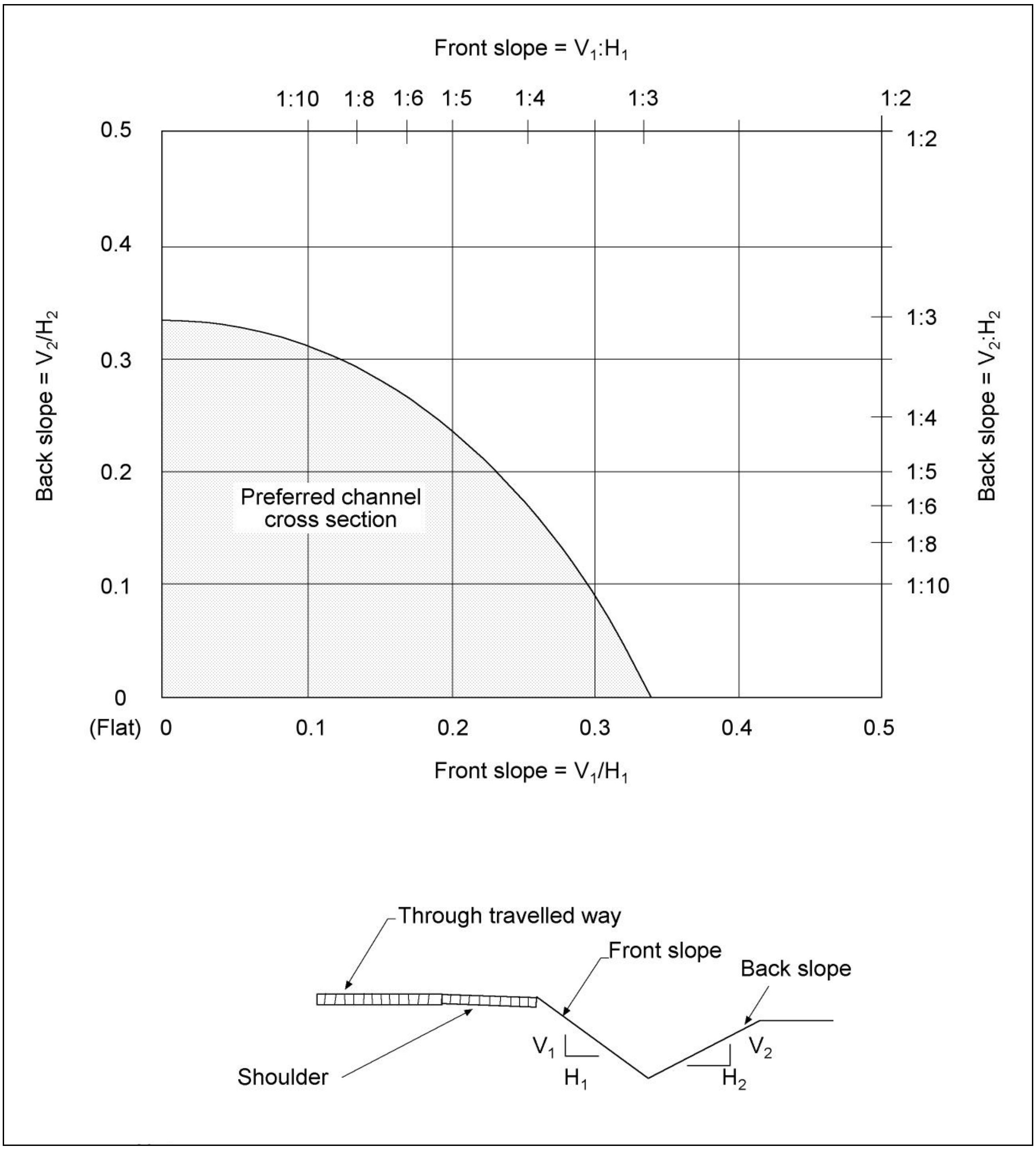
Drain sections that fall outside the shaded area of Figures 2.11 and 2.12 are considered non-traversable. As a general rule, these drains should either be:

- reshaped
- converted to a closed system (culvert or pipe)
- located beyond the clear zone
- where appropriate, shielded with a safety barrier.

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

- restrictive right-of-way
- rugged terrain
- resurfacing, restoration or rehabilitation projects where these works result in an unavoidable change to the shape of a drain and 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. This increases the probability of impact with any fixed objects present on the bottom or side slopes of the drain. Breakaway hardware may not operate correctly if the vehicle is airborne or sliding sideways when contact is made. For these reasons non-yielding fixed objects or non-frangible posts should not be located on the side slopes or bottom of drains.

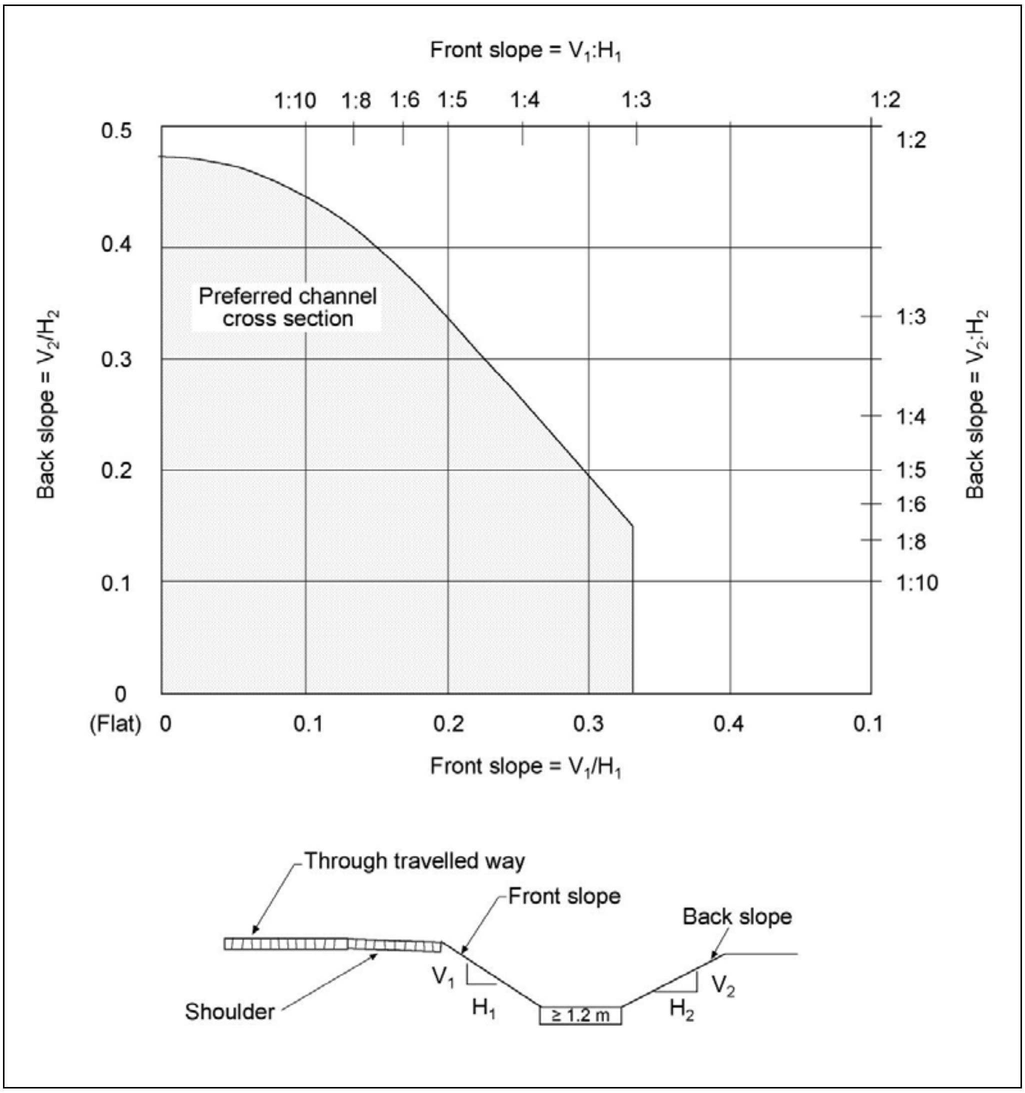


Note: This chart is applicable to all 'V' drains, rounded channels with bottom widths less than 2.4 m and trapezoidal channels with bottom widths less than 1.2 m.

(Source AASHTO 2002)

Figure 2.11 — Preferred Cross Sections for Drains with Abrupt Slope Changes

If the slope between the roadway and the base of the back slope is 1:3 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 normally includes rock cuts with a rough face that can cause excessive vehicle snagging. Examples of clear zone determination for drains and drain back slopes are provided in Appendix C.



Note: This chart is applicable to rounded channels with bottom widths of 2.4 m or more and to trapezoidal channels with bottom widths equal to or greater than 1.2 m.

(Source: AASHTO 2002)

Figure 2.12 — Preferred Cross Sections for Drains with Gradual Slope Changes

2.6.5 Culverts

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 drain cross sections described in 2.6.4 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, may also present a hazard to vehicle occupants.

Traditionally culverts have been designed with concrete headwalls and wingwalls that either have resulted in a potential roadside hazard or required shielding with safety barrier. In such cases, the options to remove or reduce the hazard caused by these obstacles are (AASHTO, 2002):

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

If a front slope 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 front 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 front slopes is also desirable because it:

- results in a very small target
- 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 barrier).

As a significant percentage of errant traffic may travel beyond the clear zone (refer section 2.4.7) and an obstacle at this location may still be a hazard. Extending culverts to the clear zone limit without providing a traversable end is therefore not preferred, particularly on high-speed roads. This option may also 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 limit.

Large culverts (single pipe > 900 mm diameter, multiple pipes > 750 mm diameter) should be assessed and treated taking into account factors, such as the volume of traffic, the height of drop associated with the culvert, the culvert size, and the distance between the headwall and the edge of traffic lanes.

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, 2002) that cars can cross grated culvert end treatments on slopes as steep as 1 on 3, 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. Such a treatment is illustrated in Figure 2.13. 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.

In some instances it may be appropriate not to treat the end of a culvert at all, and to simply provide adequate delineation. Typically this may be an option on low volume roads where traffic barriers may result in a higher risk to road traffic than not providing any barrier, or at low-level bridges subject to frequent flooding. Designers should refer to AS 5100.1 - 2004 for guidance regarding barriers on bridges.

Where endwalls must be provided at right angles to the direction of traffic, for example on culverts under driveways or median cross-overs, driveable endwalls should be used (refer to example in Figure 2.13).

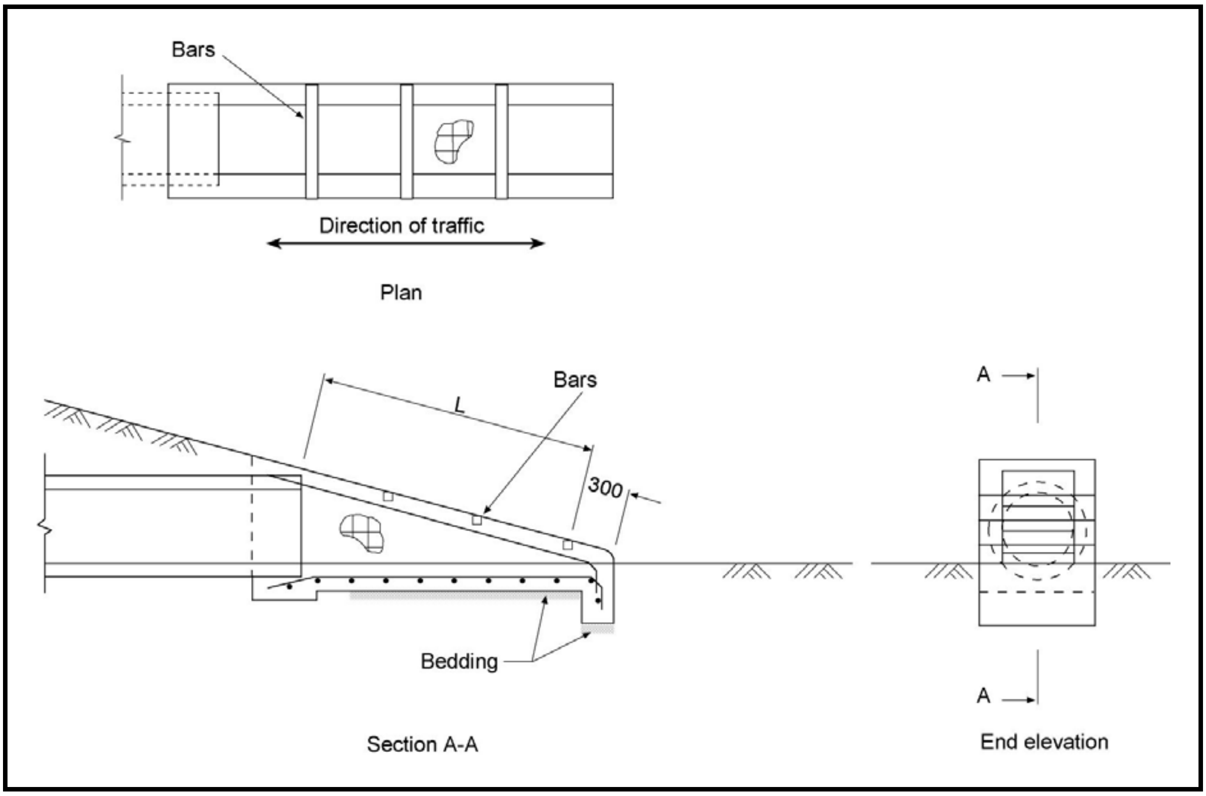


Figure 2.13 — Driveable Culvert End Wall for a Small Pipe

2.6.6 Bodies of Water

Bodies of water should be evaluated with respect to the degree of potential hazard they pose (NY 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
- 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.

The designer should visualize the paths that errant vehicles are likely to take in reaching the water. If the water hazard is substantial and there is a high likelihood of errant vehicles reaching the water, the designer should consider measures to prevent access by an errant vehicle to that watercourse.

3. SAFETY BARRIER PERFORMANCE STANDARDS

3.1 Introduction

Roadside safety barrier systems should be considered for use only if they meet the requirements of AS/NZS 3845:1999 – Road Safety Barrier Systems.

The performance goal of a longitudinal safety barrier, end treatment or crash attenuator (i.e. terminal) is that when under impact by the design vehicle it will:

- safely contain and redirect the vehicle away from the hazardous area
- decelerate the vehicle to a stop over a relatively short distance
- allow a controlled penetration of the barrier

without causing serious injury to the vehicle's occupants, other road users, or work zone personnel. Crash testing is undertaken to demonstrate that safety barrier treatments and products meet this goal.

Many different types of barriers have been developed worldwide, but historically barriers used in Australia have been developed and tested in the United States of America. The requirement for costly testing and availability of proprietary products are two factors that influenced this practice. Also the limited and geographically dispersed demand precludes the economic use of too many varieties of barrier. In addition, attention to uniformity of design detailing can lead to significant economies in construction and maintenance, and consideration of maintenance requirements at the initial design/selection stage can lead to long term overall cost savings. Designers should therefore establish the practice of the relevant jurisdiction when selecting and designing a barrier.

3.2 Crash Test Procedures

3.2.1 General

The United States of America has a set of tests developed as part of the National Cooperative Highway Research Program, published in Report 350 (NCHRP, 350, 1993). The crash test procedures required by AS/NZS 3845:1999 are based on the Federal Highway Administration (FHWA) NCHRP 350 (1993) report and Australian jurisdictions generally require compliance with NCHRP 350, or other equivalent procedures.

While this guide is primarily concerned with safety barriers, it should be noted that NCHRP 350 (1993) provides a wide range of test procedures to permit safety performance evaluation of not only barriers, end treatments (i.e. terminals) and crash attenuators, but also breakaway support structures and utility poles, truck mounted attenuators and work zone traffic control devices. Details of crash tested barriers, end treatments, transitions and other road furniture, as well as details of any restrictions on their use is available on the FHWA website (http//safety.fhwa.dot.gov/fourthlevel/pro res road nchrp350.htm).

The European Committee for Normalisation (CEN) also has established performance criteria for safety barriers and crash attenuators CEN (1998). However, the vehicle used for the lower test levels (refer Table 3.3) is lighter than that used in NCHRP 350 (1993) tests. Designers should consider this and all other relevant issues if considering European products for use in Australia. A comparison of USA and European test requirements is provided in Section 3.2.2.

Acceptance of a roadside safety barrier system is based on an evaluation of its performance in an idealised crash test (vehicle in tracking mode; approach surface flat, paved and free from obstructions such as kerbs) for a specific weight and type of vehicle at designated speeds and impact angles.

Whilst AS/NZS 3845:1999 adopts the six test levels, TL1 to TL6, from NCHRP 350 (1993) (Refer Table 3.1), it supplements them with a further test level TL0. This additional test level provides for a 1600 kg car impacting at 50 km/h at an angle of 25°.

The evaluation criteria shown in Table 3.2 are applied to any test level described in Table 3.1. They are based on key evaluation factors that are pertinent to a successful barrier system, namely:

- structural adequacy of the barrier system
- occupancy risk and the impact velocity and ride down acceleration limits
- vehicle trajectory after impact.

The tests summarised in Table 3.1 are applied both to longitudinal barriers generally along the length and at transitions between barrier types. The designer should be aware that conditions at a particular site when a vehicle crashes into a safety barrier are likely to be different from those constructed at a test site. Key factors that may differ are:

- general site conditions such as the slope at the edge of road and shoulder maintenance
- the dynamics of the errant vehicle are unlikely to replicate tests where the vehicle is ‘free wheeling” without brakes applied, traveling at uniform speed and at a predetermined angle (refer Section 3.3)
- ground conditions for the support of posts may be different from sites at which barrier tests are conducted.

As tests provide the means to verify satisfactory in-service performance of barriers, it is essential that barrier installations replicate critical conditions that apply in tests. This is achieved through the consistent application of guidelines, standards, and manufacturer’s specifications. However, because of the variation in conditions that occur in roadside environments, judgement must be exercised in the application of test results to practice, and the performance of safety devices and products (including barriers) should be monitored in the field to ensure that they operate as intended.

3.2.2 Comparison of USA and European Test Requirements

As discussed in Section 3.2.1 European barrier performance criteria (EN 1317) provide a set of tests that may be compared to the USA NCHRP 350 (1993) requirements. For ease of comparison testing requirements that are similar have been aligned, wherever possible, in Table 3.3. It can be seen from the table that the NCHRP 350 (1993) testing procedure differs from EN 1317, particularly with respect to the use of a heavier passenger vehicle.

The test levels shown in Table 3.3 are compared on the basis of impact severity, computed from an Impact Severity Formula. This formula is based on the principle of kinetic energy and the Impact Severity (IS) is given by:

$$IS = \frac{1}{2} M \left[V \left(\sin \theta \right) \right]^2$$

where:

M = mass of vehicle in kg;

V = velocity in m/s;

θ = impact angle is in degrees; and

IS = impact severity in joules.

This formula computes the kinetic energy that is imparted at right angles to the safety barrier and must be absorbed by the barrier. It can be seen from Table 3.3 that when comparing NCHRP 350 (1993) TL3 to N2, the amount of energy generated by the impact under NCHRP 350 (1993) is 68% more than that generated for the containment level N2. Under EN 1317 the test vehicle is lighter and impacts at a shallower angle, although the impact speed is 10 km/hr more than the TL3 test under NCHRP 350.

Not only can the impact severity formula be used for comparing different test conditions but it also gives an indication of the implications for vehicles of different masses travelling at different speeds. For example, the same energy would be created for a:

- 10,447 kg vehicle travelling at 70 km/hr impacting at 15° as that for TL4 (i.e. 8000 kg vehicle at 80 km/hr with a 15° impact angle)
- 5,120 kg vehicle travelling at 100 km/hr impacting at 15° as that for TL4 (i.e. 8000 kg vehicle at 80 km/hr with a 15° impact angle)
- 23,000 kg vehicle travelling at 100 km/hr impacting at 15° as that for TL5 (i.e. 36,000 kg vehicle at 80 km/hr impacting at 15°)
- 19,000 kg vehicle travelling at 110 km/hr impacting at 15° as that for TL5 (i.e. 36,000 kg vehicle at 80 km/hr impacting at 15°).

It should be noted that the formula only compares the energy created, however different vehicles have a different centre of gravity and therefore a higher vehicle could overturn even if the barrier could withstand the same impact. Nevertheless, it allows designers to acquire an appreciation of the effects of different mass vehicles, impact angles and speeds.

AS/NZS 3845:1999 requires barriers used in Australasia to be successfully tested in accordance with NCHRP 350 (1993) or to be “deemed to comply’ under the standard. It does not preclude the use of other materials or products not specifically referred to in the document. It requires that substitution shall only occur with the agreement of both the agency (road authority) and the manufacturer.

3.3 Test Vehicle

The test levels in Table 3.1 are almost identical to those used in NCHRP 350. The test vehicles range from a 2000kg pickup truck to a 36000 kg tanker. The test vehicle may be pushed, towed or self powered to the test speed and managed so that it is "freewheeling" at the time of impact with the barrier. The application of brakes should be delayed as long as safely feasible to establish the un-braked runout trajectory. The test vehicle should be guided to impact the barrier at the required angle and the steering wheel should not be constrained. Designers should understand that the conditions existing at the time of impact during a real crash on a public road would be quite different to these test conditions.

Safety barriers must meet the test level that is appropriate to the particular site conditions. Where impact speeds are higher than 70 km/h, safety barrier systems selected by designers should at least meet Test level 3 (TL3). However, standard height concrete barriers and Thrie-Beam safety barriers that have passed TL4 tests and taller concrete barriers that have passed TL5 (height 1070 mm) or TL6 may be used where a higher level of containment is justified. Except for barriers associated with bridges (refer to AS 5100:2004) and situations where the consequences of vehicles leaving the road would be catastrophic, safety barriers are not normally designed to contain van or tanker type semi-trailers (TL5 and TL6). In lower speed environments a barrier meeting TL2 may be appropriate.

Table 3.1 — Test Levels for Longitudinal Barriers (TL- 0 to TL- 6)

Test Level	Vehicle Mass (kg) and Type	Speed (km/h)	Angle (degrees)	Height of Centre of Gravity (mm)
0	820 C	50	20	550
	1 600 C	50	25	550
1	820 C	50	20	550
	2 000 P	50	25	700
2	820 C	70	20	550
	2 000 P	70	25	700
3	820 C	100	20	550
	2 000 P	100	25	700
4	820 C	100	20	550
	8 000 S	80	15	1 250
	820 C	100	20	550
	36 000 V	80	15	1 850
6	820 C	100	20	550
	36 000 T	80	15	2 050

(Source: AS/NZS 3845:1999)

LEGEND:

C = small car

P = four wheel drive or utility truck

S = single-unit van truck

T = tanker type semi-trailer

V = van type semi-trailer

Notes:

1. Refer NCHRP 350 (1993) for Test Level Procedure
2. TL- 3: High-speed arterial roads
   TL- 2: Local and collector roads
   TL- 0 and 1: Work zones and low speed roads
   TL- 4 to 6: Truck and other heavy vehicles

Table 3.2 — Safety Evaluation Guidelines

<table>
<tr><th>Evaluation Factors</th><th colspan="2">Evaluation Criteria</th></tr>
<tr><td rowspan="3">Structural Adequacy</td><td>A.</td><td>Test article should contain and redirect the vehicle; the vehicle should not penetrate, under ride or override the installation although controlled lateral deflection of the test article is acceptable.</td></tr>
<tr><td>B.</td><td>The test article should readily activate in a predictable manner by breaking away, fracturing or yielding.</td></tr>
<tr><td>C.</td><td>Acceptable test article performance may be by redirection, controlled penetration or controlled stopping of the vehicle.</td></tr>
<tr><td rowspan="7">Occupant Risk</td><td>D.</td><td>Detached elements, fragment or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment or present an undue hazard to other traffic, pedestrians or personnel in a work zone. Deformations of, or intrusion into, the occupant compartment that could cause serious injuries should not be permitted.</td></tr>
<tr><td>E.</td><td>Detached elements, fragments or other debris from the test article or vehicular damage should not block the driver's vision or otherwise cause the driver to lose control of the vehicle.</td></tr>
<tr><td>F</td><td>The vehicle should remain upright during and after collision although moderate roll, pitching and yawing are acceptable.</td></tr>
<tr><td>G.</td><td>It is preferable, although not essential, that the vehicle remain upright during and after collision.</td></tr>
<tr><td>H.</td><td>Occupant impact velocities should satisfy the following:
<table>
<tr><th colspan="3">Occupant Impact Velocity Limits (m/s)</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and lateral</td><td>9</td><td>12</td></tr>
<tr><td>Longitudinal</td><td>3</td><td>5</td></tr>
</table></td></tr>
<tr><td>I.</td><td>Occupant ride down accelerations should satisfy the following:
<table>
<tr><th colspan="3">Occupant Ride down Acceleration Limits (G's)</th></tr>
<tr><th>Component</th><th>Preferred</th><th>Maximum</th></tr>
<tr><td>Longitudinal and Lateral</td><td>15</td><td>20</td></tr>
</table></td></tr>
<tr><td>J.</td><td>(Optional) Hybrid III dummy. Response should conform to evaluation criteria of Part 571.208, Title 49 of Code of Federal Regulations, Chapter V (10-1-88 Edition)</td></tr>
<tr><td rowspan="4">Vehicle Trajectory</td><td>K.</td><td>After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.</td></tr>
<tr><td>L.</td><td>The occupant impact velocity in the longitudinal direction should not exceed 12 m/s and the occupant ride down acceleration in the longitudinal direction should not exceed 20 G's.</td></tr>
<tr><td>M.</td><td>The exit angle from the test article preferably should be less than 60% of test impact angle, measured at time of vehicle loss of contact with test device.</td></tr>
<tr><td>N.</td><td>Vehicle trajectory behind the test article is acceptable.</td></tr>
</table>

(Source: NCHRP 350)

Table 3.3 — Comparison of AS/NZS3845:1999 and EN1317 Test Requirements

AS / NZS 3845						EN 1317					
Test Level	Mass (kg)	Type	Speed (km/hr)	Angle (Degrees)	Impact Severity (kJ)	Test Level	Mass (kg)	Type	Speed (km/hr)	Angle (Degrees)	Impact Severity (kJ)
0	820	C	50	20	9.3						
	1600	C	50	25	27.6						
1	820	C	50	20	9.3						
	2000	P	50	25	34.5						
2	820	C	70	20	18.1						
	2000	P	70	25	67.5						
						N1	1500	C	80	20	43.3
3	820	C	100	20	37.0	N2	900	C	100	20	40.6
	2000	P	100	25	137.8		1500	C	110	20	81.9
4	820	C	100	20	37.0						
	8000	S	80	15	132.3						
						H1	900	C	100	20	40.6
							10000	R	70	15	126.6
						H2	900	C	100	20	40.6
							13000	B	70	20	287.5
						H3	900	C	100	20	40.6
							16000	R	80	20	462.1
						H4a	900	C	100	20	40.6
							30000	A	65	20	572.0
5	820	C	100	20	37.0						
	36000	V	80	15	595.4						
6	820	C	100	20	37.0	H4b	900	C	100	20	40.6
	36000	T	80	15	595.4		38000	A	65	20	724.6

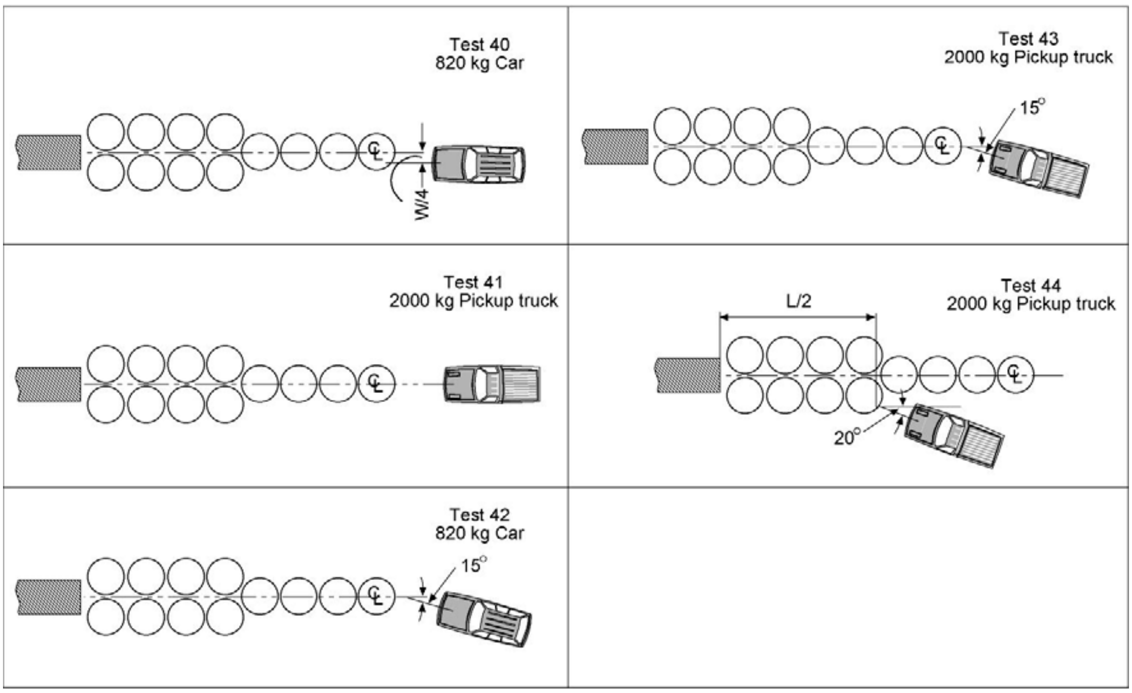
Legend to Table 3.3.

AS/NZS 3845 Test Vehicles:	EN1317 Test Vehicles:
C = Small car	A = Articulated Heavy Goods Vehicle
P = Four wheel drive or utility truck	B = Bus
S = Single unit van truck	C = Car
T = Tank type semi trailer	R = Rigid Heavy Goods Vehicle
V = Van type semi trailer	

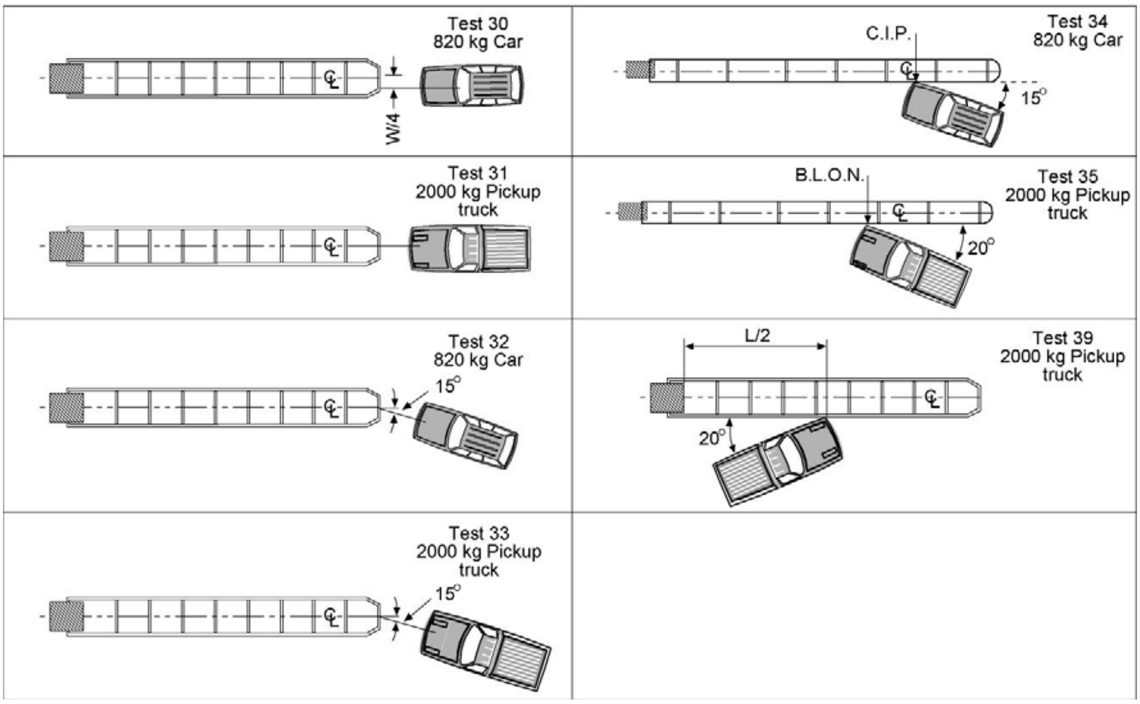
3.4 Testing of End Treatments

The test criteria for end treatments require that the impacting vehicle is gradually stopped or redirected by the end treatment or crash attenuator when impacted end-on. In addition to end-on impacts, barrier end treatments and crash attenuators must be capable of safely redirecting a vehicle that impacts the side of the device, both at mid-length and near the nose (AASHTO 2002). Most commercially available end treatments meet Test Level 3 TL3 (a 2000 kg pickup truck impacting the end treatment at 100 km/h at a 25 degree angle, whilst some meet TL2 (2000 kg pickup truck at 70 km/h and a 25 degree impact angle). Special crash attenuator designs can be produced to meet higher impact speeds but the cost and size may be prohibitive.

Part of the testing associated with meeting AS/NZS 3845:1999 requires that errant vehicles crashing into an end treatment must remain stable during and after an angular or head-on collision, and be directed away from the potentially hazardous safety barrier and the hazard shielded by the barrier. If this is achieved during crash testing, the terminal is considered to have performed properly and is considered to have met the vehicular parameters of crashworthiness. Figure 3.1 illustrates examples of various impact test conditions for “non-redirective” and “redirective” (refer Section 8) end treatments as shown in NCHRP 350. Other test parameters include occupant deceleration values that need to be below damage thresholds.



(a) Non-Redirective Terminals



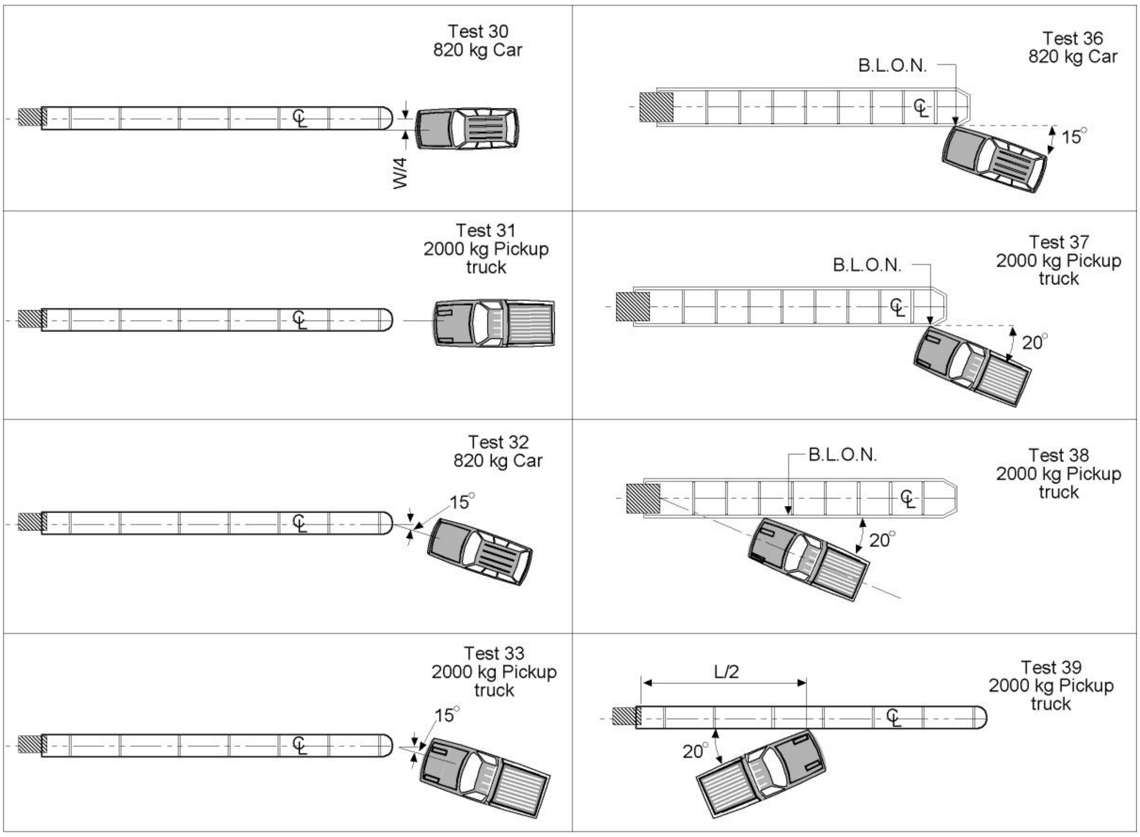
Note:

CIP denotes the critical impact point

BLON denotes the beginning of the length of need

(b) Gating / Redirective Terminal

Figure 3.1 — Test Conditions for Crash Attenuators



Note: BLON denotes the beginning of the length of need

(c) Non-Gating/Redirective Terminal

(Source: NCHRP 350, 1993)

Figure 3.1 — Test Conditions for Crash Attenuators (terminals)

4. LONGITUDINAL BARRIER TYPES, SELECTION AND DESIGN

Safety barrier systems can generally be divided into three broad types comprising rigid, semi-rigid and flexible barriers. Each type performs differently under impact and has characteristics that may result in it being advantageous in certain situations.

All barriers used in Australia should comply, or be “deemed to comply” with AS 3845:1999. However, AS/NZS 3845:1999 “is not to be interpreted to mean that it prevents the use of materials or products not specifically referred to” in the document. The Standard requires that use of alternative material and products only occurs with the agreement of both the road agency and manufacturer.

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, situations often arise where it is necessary to provide a rigid or semi-rigid barrier, and in some cases a barrier that will contain large semi trailers.

Special barrier designs have been developed for use along roads where:

- the aesthetic appearance of the roadside is important
- there is a need to cater for vulnerable road users.

However, special barriers for these purposes have not been used to a large extent in Australia. The barriers included in this section are those most widely used by road authorities throughout Australasia.

Rails or other fittings should not be attached to road safety barrier systems unless they have been suitably crash tested, or operational experience indicates that they do not affect performance of the barrier system or increase the risk to either occupants of the impacting vehicle or passers-by.

Road safety barrier products are continually being improved or developed and designers must be aware of the range of suitable products that are available. Some of these products will have been developed based on the European testing regime that uses lighter vehicles than NCHRP 350. In addition, road authorities may adopt a range of products while having due regard for barrier maintenance logistics (e.g. it may not be practicable to carry “spare parts” for a large number of different products).

4.1 Types of Barrier

4.1.1 Flexible Barrier Systems

Flexible Barrier Systems are used to describe wire rope barrier systems because of the relatively large deflections that occur during vehicle impacts with these barriers.

There are a number of wire rope barrier systems that have been accepted for use in Australia. They are all proprietary brands based on a similar principle but the details of design differ. Designers should refer to manufacturers’ or distributors’ manuals or specifications to acquire accurate and current guidelines on design and installation of the particular barrier product.

Designers should also consult the relevant jurisdiction in each State or Territory of Australia and in New Zealand to establish the barriers that are acceptable within the particular jurisdiction and consider the various characteristics of each system in determining the type of system to be used.

Wire Rope Barrier Systems comprise wire ropes (generally 3 or 4 cables) supported on weak posts that are installed primarily to support them. The wire ropes are anchored at each end and can be anchored at intervals along the barrier, and tensioned in accordance with manufacturer's specifications. The design enables the cables to readily strip from the frangible posts during impact, thereby minimising snagging and ensuring that the vehicle is smoothly redirected. Upon impact a number of posts break away from the wire rope and the kinetic energy of the vehicle is dissipated through the deflection of the wire rope.

Following an average impact, the maintenance activities and costs associated with repairing wire rope barriers are minimal. It is only the damaged posts that need to be replaced. The wire does not usually need to be re-tensioned. These flexible systems are suitable for either roadside or median applications.

Designers and installers need to be mindful of the deflections exhibited when these types of systems are involved in collisions. These systems exhibit larger deflections than other barrier types and greater clearances must be provided within medians, and between the barrier and the hazards it is shielding. It is also very important that the area behind the barrier within the likely deflection distance should be flat and no steeper than 1 on 10 (i.e. 1 vertically to 10 horizontally).

Both European and American systems exist and the cable arrangements and heights differ. Tests have been carried out for the different configurations in accordance with the relevant testing regime (refer Chapter 3).

Wire Rope Safety Barrier in a Wide Flat Median

Only systems that have been tested to meet NCHRP 350 (1993) or equivalent are to be used in Australia. Field performance has shown that barrier penetration is minimal with even large high-speed trucks being safely contained and redirected. There have been only a few reports around Australia of wire rope safety barrier (WRSB) being breached by impacting vehicles and each case involved excessively high speed or other extenuating circumstances.

Where barrier end treatments have not passed the NCHRP 350 (1993) TL3 testing, the FHWA has stipulated that the end treatment for the barrier should either be terminated outside of the clear zone or protected with a suitable device such as a sand barrel array. However, end treatments have been used within clear zones in Australia for many years without serious recorded incidents.

Wire rope safety barriers are proprietary products and hence the design of them varies. They generally have the following features and properties:

- Three or four cables arranged in different configurations and at different heights.
- The installation height of a wire rope safety fence is an important consideration. The design height varies depending on the system, the upper cable typically being 580-720 mm above ground level. Where the slope of the verge is 1 on 10 or flatter, the height to the top cable is measured from the pavement edge level if the barrier is located within 1.5 m of the edge of carriageway. For those situations when the barrier is 1.5 m or more from the edge of the travel lane and the verge is 1 on 10 or flatter, the height to the top cable is measured from the ground level at the base of the post.
- Posts of a particular cross-sectional shape peculiar to the product (e.g. square, oval shape).
- The function of the posts is to support the cables and to dissipate some of the energy of vehicle impacts through deformation of the posts.
- A typical post spacing is 2.5 m or 3.2 m, however, tests have been carried out at various post spacings. A smaller post spacing (e.g. 1.2 m) may be used where it is desired to reduce deflection of the system adjacent to hazards.
- Steel posts may be driven or placed in concrete sockets that allow easy withdrawal of the posts when they are damaged. Plastic sleeves are available to form the sockets.

Wire Rope Barrier Systems are generally seen to be more aesthetically pleasing through their open design that also prevents accumulation of drifting snow and sand, where this is a consideration.

4.1.2 Semi-rigid Barrier Systems

Semi-rigid safety barriers mainly include systems that have a steel beam attached to blockouts that are supported on either wooden or steel posts. These barriers deform substantially under impact but have less deflection than flexible systems. The forms of semi-rigid barrier that have been commonly used in Australia are shown in Table 4.1:

Table 4.1 —Semi-Rigid Barrier Test Levels

Semi-Rigid System	Test Level
W-Beam steel barrier (Blocked-out Strong Post) Type G4	3
Thrie-Beam steel barrier Type G9	3
Modified Thrie-Beam steel barrier	4

Note: The Thrie-Beam has steel blockouts and the Modified Thrie-Beam has modified steel blockouts.

The W-Beam is widely used as a general purpose system in speed zones up to 110 km/h where the design vehicle is not a truck. The Thrie-Beam is intended for locations where barrier is regularly hit, the stronger rail making it less prone to damage during low and moderate speed impacts. It is also suitable for use where there is a higher probability that it will be impacted by heavy vehicles as the higher rail increases its ability to contain vehicles larger than passenger cars under some impact conditions. The Modified Thrie-Beam was developed to improve the performance of the Thrie-Beam in impacts by heavy vehicles and is used where there is a higher than normal likelihood of heavy vehicle impacts. In Australia these barriers, shown in Figure 4.1, are constructed using either steel or timber posts. While the W-Beam and the modified Thrie-Beam as detailed in AS/NZS 3845:1999 have not been crash tested to NCHRP 350, these barriers are "deemed to comply" under AS/NZS 3845:1999. The height of W-Beam and Thrie-Beam barrier is measured to the top of the rail.

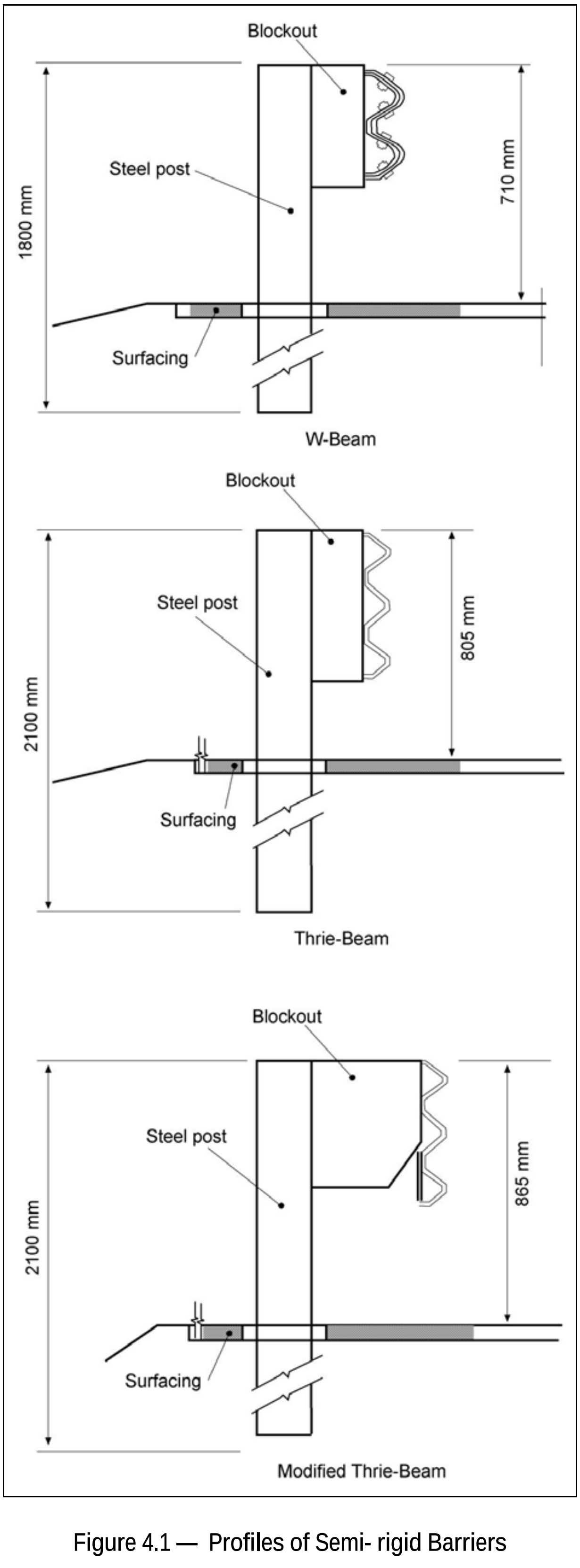


Figure 4.1 — Profiles of Semi- rigid Barriers

Semi-rigid barriers redirect colliding vehicles by the impact forces being absorbed by the system through bending of the support posts and development of tensile forces in the barrier rail, which deforms and redirects the vehicle. Because these systems are stiffer than flexible systems, resistance is achieved through the combined flexure and tensile strength of the rail. The undamaged adjacent posts provide support for the beam during impact.

As the development of tension in the beam is dependent on the correct installation of the end anchorages, it is important that they are installed in accordance with relevant standard drawings and specifications based on AS/NZS 3845:1999. Post spacing is generally 2.0 m, as defined in AS 3845. A reduction in the spacing of posts or the use of two W-Beam rails (nesting) may be implemented to strengthen and stiffen the barrier and hence reduce deflection where an isolated hazard is within the normal deflection limits of the beam.

Satisfactory barrier performance is dependent on the beam being installed and maintained at the correct height and a generally flat and smooth approach slope (no steeper than 1 on 10) being provided. The barrier should always be blocked out using correctly installed blockouts to reduce the likelihood of vehicles “snagging” on the posts.

Where minor adjustment of the post position away from the traffic lane is required to avoid an obstacle (e.g. edge of pit) an additional blockout may be used at one isolated post. No more than two blockouts shall be used on a post. It will usually be preferable in these situations to leave the post out and increase the stiffness of the system by nesting the rail.

Rail to blockout bolt washers should not be installed for W-Beam, Thrie-Beam or Modified Thrie-Beam systems, as they will cause the rail to ride down during severe impact, leading to the possibility of vehicles vaulting the barrier after impact. These washers are not necessary for strength over the normal operating range of crashes and their deletion keeps rail heights relatively constant during severe crashes thus ensuring the system operates more effectively. To reduce twisting of Thrie-Beam and Modified Thrie-Beam rails, the rail to blockout bolts should alternate between the top and the bottom indentations of the rail.

W-Beam Steel Barrier (Blocked Out Strong Post) Type G4

Traditionally, the blocked-out steel W-Beam barrier has been the most commonly used barrier in Australia. It consists of a steel beam of W-shape cross-section attached to blockouts supported on posts. Several acceptable designs have been used in the USA.

A common system using steel posts and steel blockouts (both “I” sections) failed to meet the minimum test level for general use on roads, NCHRP Report 350 evaluation criteria at Test Level 3, when a pickup truck snagged on a post and subsequently overturned. In-service experience with this system also demonstrated a tendency for the rail to tear on the blockouts (AASHTO 2002, Section 5.4.1.5). AASHTO (2002) therefore recommends that systems that have steel posts be provided only with routed wood or recycled plastic blockouts (150 mm x 200 mm) that fit snuggly over the steel post. This arrangement has passed NCHRP 350 (1993) at the TL-3 level. In Australia systems using steel “C” channel for both posts and blockouts have been found to perform satisfactorily and are “deemed to comply” with NCHRP 350 (1993) at the TL-3 level.

AASHTO also notes that concrete posts were used in early years but were not successful.

Under substantial impact, properly installed W-Beam barrier has been designed to behave as follows:

- The W-Beam first bends and then flattens out forming a wide tension band to contain the impacting vehicle.
- The posts are initially restrained by passive pressure in the soil, resulting in local failure of the soil at the ground line and for a short distance below.
- Wooden posts rotate, with their point of rotation some distance below the ground. Steel posts partially rotate, but also bend near the ground line.
- Deflection of the posts and blockouts causes the line of action of the restraining force acting on the side of the vehicle initially to rise, before ultimately dropping thus minimising the risk of the vehicle vaulting or rolling over. The blockouts also lessen the risk of vehicle wheels snagging on the posts.
- The posts eventually yield and the rail tears away from the bolt heads and restrains the vehicle by tension.
- The barrier deflection lessens the rate of change of momentum of the impacting vehicle and its occupants and this can significantly reduce vehicle damage and personal injury.

Sometimes, however, a stiffer barrier is required, capable of giving more restraint to heavy vehicles, or of limiting deflections on impact; e.g. narrow medians on roads with restricted cross-section. W-Beam barrier may not be appropriate in such situations.

Thrie-Beam Steel Barrier (Blocked Out Strong Post) Type G9

The Thrie-Beam barrier is stiffer than the W-Beam as a result of the increased depth of the beam element. This type of rail has two indentations, compared with the one indentation possessed by the W-Beam. The high cost of this barrier has prevented its use in Australia until recent years and continues to be an important consideration.

The post spacing for Thrie-Beam blocked-out (strong post) should be 2 m, in accordance with AS/NZS 3845:1999. The height of a Thrie-Beam with standard blockouts is 805 mm (plus or minus 20 mm) measured to the top of the rail.

The blockouts also enhance the performance of the barrier for crashes by heavy vehicles and this barrier is particularly suitable for use at locations where there is a high frequency of crashes by heavy vehicles. The comments in AASHTO (2002) relating USA experience with the use of wood or recycled plastic (rather than steel) blockouts for W-Beam barrier also apply to Thrie-Beam barriers. However, steel "C" channels are also used successfully in Australia for Thrie-Beams.

W-Beam on Approach to Bridge

A Thrie-Beam system with wooden posts and wooden blockouts, and a top railing height of 805 mm, was successfully tested to TL3, containing and redirecting a 2000 kg pickup truck impacting at about 100 km/h and at an angle of 24°. A system using steel posts and wooden blockouts also passed the same test. In an earlier test to establish an upper performance level, a system using steel posts and steel blockouts contained and redirected a 9100 kg school bus, although it failed to keep the bus upright during the test (AASHTO 2002).

The greater rail height for this barrier requires sight distances to be checked for adequacy.

Transition pieces are available for connection to W-Beam.

Existing standard Thrie-Beam installations may be retained if they are deemed to be providing a satisfactory level of service. However, because of concerns about their performance for light cars the Modified Thrie-Beam design is generally preferred for new installations.

Modified Thrie-Beam Steel Barrier

The modification is a steel blockout (430 mm high by 350 mm deep) constructed from a steel section with a triangular notch cut from its web (refer to Figure 4.1). This allows the lower portion of the Thrie-Beam and the flange of the blockout to bend when hit and results in small vehicles being redirected less severely in collisions, and also maintains the rail at the correct height during impact. This characteristic is essential for guardrail situations on high volume roads carrying a significant percentage of both heavy vehicles and light passenger vehicles, for example, highways approaching regional centres.

Modified Thrie-Beam guardrail meets Test Level 4 (8000 kg at speeds of 80 km/h and crash angles of 15°). Upon impact, the rail remains nearly vertical in the collision area and the posts are pushed backwards. Rail to blockout bolt washers should not be used (see comments on Thrie-Beam). The height of a Modified Thrie-Beam is 865 mm measured to the top of the rail.

4.1.3 *Rigid Barrier Systems*

Rigid safety barriers are basically a reinforced concrete wall constructed to a profile and height that is designed to contain and redirect errant vehicles. When impacted by a vehicle a rigid barrier experiences negligible deflection and therefore results in a more severe impact than would be experienced with a semi-rigid or flexible barrier. They should therefore be used only where impact angles are likely to be low (eg less than 15°). The types of rigid barriers that have been used in Australasia are shown in Table 4.2. The profiles of these barriers are shown in Figure 4.2.

Rigid barriers are generally only used where there is insufficient space to accommodate the deflections of semi-rigid or flexible barriers, or where there is a need to contain a heavy vehicle. However, rigid barriers must be installed with an adequate working width, measured from the face of the barrier to the face of the fixed object (refer to Figure 4.4 in section 4.2.3).

To satisfactorily contain single unit trucks, buses and other heavier vehicles, a concrete barrier must have a minimum height of about 820 mm. Articulated trucks (not including tankers) require a barrier height of 1070 mm. In such impacts the bed of the truck slides along the top of the wall applying primarily a vertical load to the top of the barrier. The tanks on tanker semi-trailers are centred about 1980 mm above the ground and there are no exposed structural elements between the wheels and the tank to apply forces to the barrier. Whilst a 1070 mm high barrier can redirect the vehicle in shallow-angle impacts, a 2290 mm high barrier is necessary to contain and redirect a tanker at higher impact angles and speeds.

Table 4.2 — Rigid Barrier Test Levels

Rigid System	Test Level (1)
New Jersey concrete barrier(2)	3 to 5
F-Type concrete barrier	3 to 5
Vertical face concrete barrier	3 to 5
Single Slope concrete barrier	3 to 5
High containment concrete barrier	5 to 6

Notes:

1. All concrete barrier profiles can be considered to meet test level 5 or 6 if they are of the required height (1070 mm for TL5 and 2290 mm for TL6) and have adequate wall reinforcement and foundations.
2. While New Jersey barrier remains in service it is no longer installed because of the likelihood of vehicle rollover when impacted by small to medium vehicles. F Type barrier is preferred.
3. Where it is desired to enhance the appearance of rigid barriers, they may be constructed from masonry or have a pattern applied provided that the surface texture is smooth enough to prevent excessive damage to impacting vehicles (refer Section 4.1.4).

It is preferable that no objects are placed on top of concrete barriers. However, where necessary road lighting poles or sign supports may be constructed into concrete barriers (e.g. in a freeway median). The poles are normally fixed to an independent foundation. While it may be practicable and economical to construct lighting poles into rigid barriers, it must be acknowledged that the poles may be impacted by semi-trailers that have a tendency to slide along the top of concrete barriers after impact. Slip base poles are not practicable or desirable in such cases because of the probability of secondary crashes involving dislodged poles.

New Jersey Barrier

New Jersey barrier has been used throughout Australia and has provided satisfactory service. For common shallow-angle impacts the shape is intended to minimise sheet metal body damage by allowing the vehicle tyres to ride up on the lower sloped face. Energy is dissipated by lifting and lowering of the vehicle, compression of the vehicle suspension and deformation of the body of the vehicle. While New Jersey barriers remain in service the shape was modified to the Type F barrier to address the adverse effects that New Jersey had on impacting small and medium vehicles during impact. Consequently, jurisdictions generally no longer install New Jersey barrier.

For higher impact angles the New Jersey shape results in a staged response by an impacting vehicle (McDevitt, 1987), namely:

- the vehicle bumper impacts the upper sloped face and slides upwards, lifting the vehicle
- as the vehicle becomes more parallel with the barrier, the wheel contacts the lower sloped face causing additional lift through compression of the front suspension
- the lifting reduces friction between the tyres and the paved surface and this facilitates banking and redirection of the vehicle.

Excessive lifting of the vehicle may cause it to yaw, pitch or roll during contact with the barrier, and to rollover when the tyres contact the road again. As wheel side rubbing forces can provide additional lift, exposed aggregate and other rough surfaces should be avoided.

The 75 mm high vertical face at the base of the New Jersey barrier is intended to provide an allowance for future pavement overlays. Apart from increasing the extent to which a vehicle is lifted, this vertical face plays no significant role in the performance of the barrier.

F Type Barrier

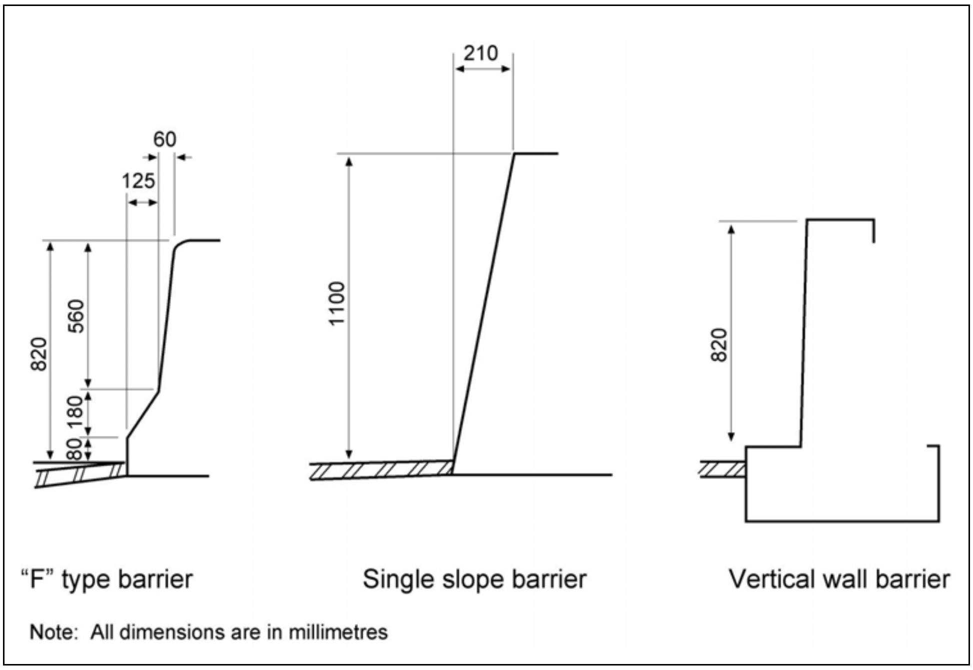
F Type barrier has a similar profile to New Jersey barrier, the main difference being that the height of the lower sloped surface is less. The major difference is that the lower slope of the F Type profile significantly reduces the lifting of an impacting vehicle, resulting in a reduced tendency for vehicles to roll, particularly small cars.

It is interesting to note that the New Jersey barrier, with a 75 mm asphalt overlay occupying the 75 mm vertical face, results in a lower sloped face that is almost identical to that of the F Type without the 75 mm overlay.

Vertical Wall Barrier

Vertical concrete barriers do not lift the vehicle and hence do not have the energy management feature of the F Type, constant slope or New Jersey barriers. Vertical concrete barrier wall can be an effective alternative to the wider safety-shape barriers and can preserve available median width at narrow locations such as in front of bridge piers. Vehicle damage in crashes with a vertical wall is greater than with safety-shaped barriers, but injuries are comparable and preservation of shoulder width is a safety benefit (AASHTO, 2002). In a crash with a vertical wall all four wheels remain on the ground and this minimises the potential for vehicles to rollover over. The trajectory of cars after they crash into vertical walls is also uncertain because wheel damage may occur as the axle contacts the barrier.

For these reasons Vertical Wall Barriers are not preferred. However they may be suitable in some situations on urban roads where road width is highly constrained or on low speed roads where the appearance of the road environment is important; for example, where it is desired to construct or face the wall using natural stone or some other material. An advantage of the vertical wall is that its profile is not affected by re-sheeting or resurfacing of the pavement.



Note: New Jersey profile not shown as F Type is generally preferred

Figure 4.2 — Profiles of Rigid Barriers

Concrete Barrier at Rear of the Left Shoulder on a Freeway

Single Slope Barrier

The need to have a single-slope barrier that has a more consistent performance than a vertical wall led to the development of single slope barriers (McDevitt, 2000). Single slope barriers can also facilitate pavement resurfacing without the profile being adversely affected.

Two types of single slope barrier have been developed. The Texas Single Slope Barrier has a wall slope of 10.8° and the Californian Single Slope barrier has a wall slope of 9.1°. These were developed by the Texas Transportation Institute and the California Department of Transport respectively.

Crash tests have indicated that the performance of the Texas Single Slope barrier is comparable to New Jersey barrier and that the performance of the Californian Single Slope barrier is comparable to that of the F Type barrier. In approving the use of Single Slope barrier, the US Federal Highway Administration (FHWA) suggested that the Californian Single Slope barrier is an improvement over both the standard New Jersey concrete barrier shape and the Texas Single Slope barrier because of the reduced vehicular climb seen upon impact and the less severe post-crash vehicular trajectories observed in crash test videos.

High Containment Barrier

To contain and redirect a tanker type semi-trailer at high angles and speeds a 2290 mm high reinforced barrier is required (refer AASHTO 2002). Because of the size, rigidity and cost of these barriers they have only been used in very special circumstances, for example where:

- a large number of tankers use the road and a sensitive roadside area such as a school play ground may be at risk
- a bridge over the road would be in danger of collapse if a tanker penetrated a barrier designed to meet a lower test level.

Summary

Although existing installations may continue to provide satisfactory service, the

- New Jersey barrier is no longer the preferred profile for use in Australasia.
- Vertical Face barrier is generally not favoured.
- F Type profile is currently the best technology available for concrete barrier.
- Californian Single Slope barrier is an acceptable alternative that may be preferred where road authorities wish to provide for future surface overlays that will not affect the barrier profile or require its replacement.

4.1.4 Aesthetic 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, 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 safety barriers. The latter systems can be designed to meet NCHRP 350 (1993) at TL3 by the provision of a continuous steel beam behind timber facing; however, there are no currently acceptable terminals available for such systems. 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 concrete single-slope barriers. Alternative textures have been tested in the USA and found to be acceptable. Some guidelines for acceptable texture have been developed (FHWA, 2002)

4.1.5 Barrier Systems for Motorcyclists

The provision of a safe road environment for all road users, including motorcyclists, is an objective of all road authorities. Although there are practical limitations on the level of improvement that can be achieved, many roads can be made safer for motorcyclists by adequate consideration of factors relating to their planning, design, construction and maintenance. Austroads Guide to Traffic Engineering Practice, Part 15 – *Motorcycle Safety (1999)* provides guidance on the road engineering factors that are important to assist motorcyclists to remain stable on their vehicles, and to provide a safer environment should they lose control or crash.

It has been suggested that the most 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 2000a). However, other barrier features that may be hazardous to motorcyclists (ATSB 2001) include:

- upper and lower W-Beam edges
- protruding reflectors
- 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
- the jagged edges of wire mesh fences, or wire mesh topped barrier systems which provide numerous lacerating surfaces, accentuating rider injury risk.

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.

Any roadside furniture item is likely to be hazardous to a motorcyclist who crashes into it, either while on the bike or when sliding along the pavement, having left the bike. Therefore designers should follow the guidance in Austroads GTEP Part 15 – *Motorcycle Safety* that includes:

- measures to assist motorcyclists remaining in control of their vehicles (e.g. adequate and consistent skid resistance, elimination of loose gravel on road surfaces)

- provision of a clear and smooth roadside (i.e. clear zone) to assist errant riders to recover or stop without serious injury
- minimising the number of 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 safety barrier is not required.

If a barrier must be provided it must be correctly designed and installed. Safety barriers that have a smooth, continuous surface and are located reasonably close to and oriented roughly parallel to the traffic stream may represent less of a safety hazard to motorcyclists. This is because they better allow the rider to slide along the surface of the barrier without the danger of impacting any sharp edges or corners that can concentrate the impact force. Also, barriers with high energy absorbing properties that allow for better energy dissipation would decrease the injury risk for fallen motorcyclists (ATSB 2000b).

A number of methods designed to improve existing 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 on the lower section of the barrier system so that motorcycle riders do not impact 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.

Road authorities would have to be assured that any devices proposed would not create other problems related to debris and drainage, and crash testing may be required.

4.1.6 Barriers for Pedestrians and Cyclists

Cyclists and pedestrians may require a barrier where hazards exist beside bicycle paths and shared paths. Special consideration may be required where a path is located immediately behind a road safety barrier. Both the height of barrier and type of barrier are important considerations.

Clause B2.3.8 of AS/NZS 3845:1999 states that "Where pedestrian facilities are incorporated behind a road safety barrier system, the desirable minimum height of the road barrier system is to be approximately 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 approximately 1400 mm". This is consistent with guidance provided in Austroads Guide to Traffic Engineering Practice, Part 14 – *Bicycles (1999)*.

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.

4.2 Barrier Selection

4.2.1 General

The number of choices available, the infinite number of real-world situations, and the multitude of variables and lack of objective criteria complicate the barrier selection process. However, this section gives 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 2002). It should also be noted that end treatments are covered in Chapter 8.

A pre-requisite to this process being commenced is that a site risk assessment and an evaluation of the economic viability of other possible countermeasures, compared to the provision of barriers, has been undertaken (refer Chapter 2).

The various factors that should be considered in selection of the type of barrier to be adopted are:

- performance capability
- deflection
- site conditions
- compatibility with adjacent barriers
- cost
- maintenance
- aesthetics
- field experience.

These factors are summarised in Table 4.3 and discussed below. In some situations environmental impact may also be a factor in the choice of barrier. For example, the 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.

4.2.2 Performance Capability

The initial determination that needs to be made is the level of containment that the barrier has to provide. That is, the traffic volume and vehicle mix need to be determined, critical site features evaluated and the consequences of barrier penetration assessed.

The factors that require consideration in assessing the design vehicle and hence the required level of containment are discussed in Section 3.3. AS/NZS 3845:1999 defines test levels for barrier systems determined by speed, impact angle and vehicle mass, summarised in Table 3.1.

Designers need to be aware that:

- there are no steel systems (i.e. Wire Rope, Thrie-Beam and W-Beam) that can meet the criteria for redirection of vehicles at Test Levels (TL) 5 or 6
- standard 810 mm high concrete barriers meet TL4. Concrete barrier systems will meet all test levels if specially designed to an appropriate strength and height
- the Modified Thrie-Beam is the only steel system that meets TL4
- vehicles of greater mass than Test Level 5 will require a special barrier system to contain them in the event that a situation exists that requires such a high level of restraint. Reference to structural designers and the provisions of AS/NZS 3845:1999 is recommended.

▪

Table 4.3 — Selection Criteria for Roadside Barriers

Criteria	Comments
1. Performance Capability	Barrier must possess sufficient structural integrity to contain and redirect design vehicle.
2. Deflection	Expected deflection of 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 planned end anchor and capable of having transition segments installed to join to other barrier systems (such as bridge railing).
5. Cost	Standard barrier systems are similar in cost, but high-performance barriers can cost significantly more.
6. Maintenance	
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.

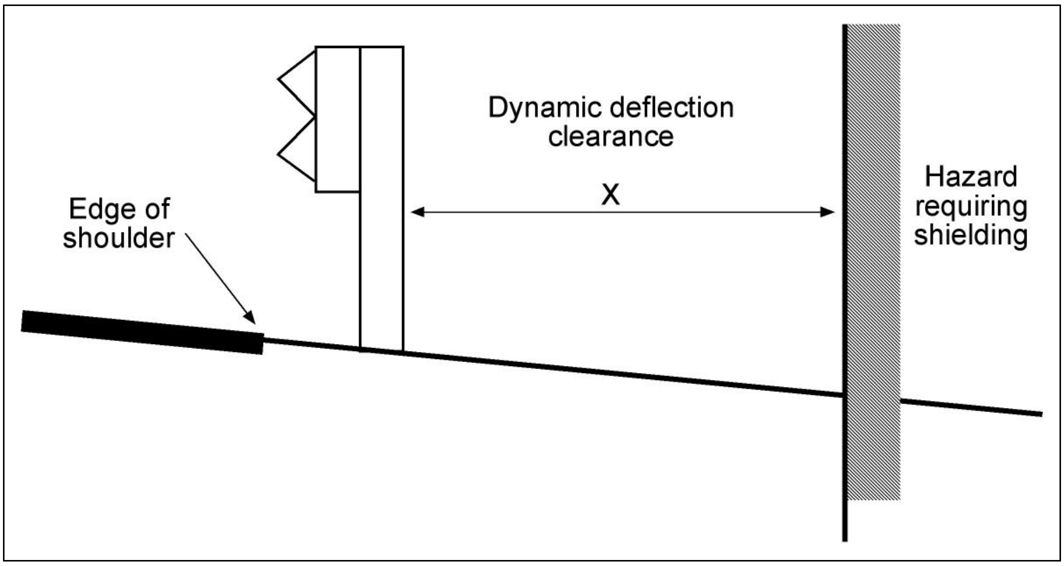
(Source: AASHTO, 2002)

4.2.3 Deflection and Clearance

Rigid barriers have negligible dynamic deflection under impact. On the other hand, semi-rigid and flexible barriers can have significant dynamic deflection under vehicle impact. Sufficient clearance must therefore be provided between the barrier and the hazard to ensure that an impacting vehicle will not also crash into the hazard with consequent injury to the occupants. The dynamic deflection clearance is illustrated in Figure 4.3. The dynamic deflection will depend on the type of barrier used and the weight, speed and impact angle of the vehicle.

Once the performance capability has been determined, the available deflection distance may dictate the type of barrier to be used. If the distance between the barrier and the shielded object or terrain feature is relatively large, a barrier that deflects significantly on impact, and imposes lower impact forces on the vehicle and its occupants, may be the best choice. If the barrier must be located immediately adjacent to the hazard, a semi-rigid or a rigid barrier may be the only choice available.

It should be noted that most 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 safety barrier (WRSB) can also be reduced by adopting a smaller post spacing.



(Source RTA 1996)

Figure 4.3 — Clearance Requirements

Table 4.4 gives an initial guide to the suitability of barrier systems in 100 km/h situations, based on deflection.

Table 4.4 — Barrier System Suitability Based on Distance to Hazard

Minimum Distance (X in Figure 4-3) from Barrier to Hazard[1]	Suitable Barrier System
1.5 m to 3.4 m	Flexible[2]
0.5 m to 1.0 m	Semi-rigid[3] Rigid
0 m to 0.5 m	Rigid

Notes:

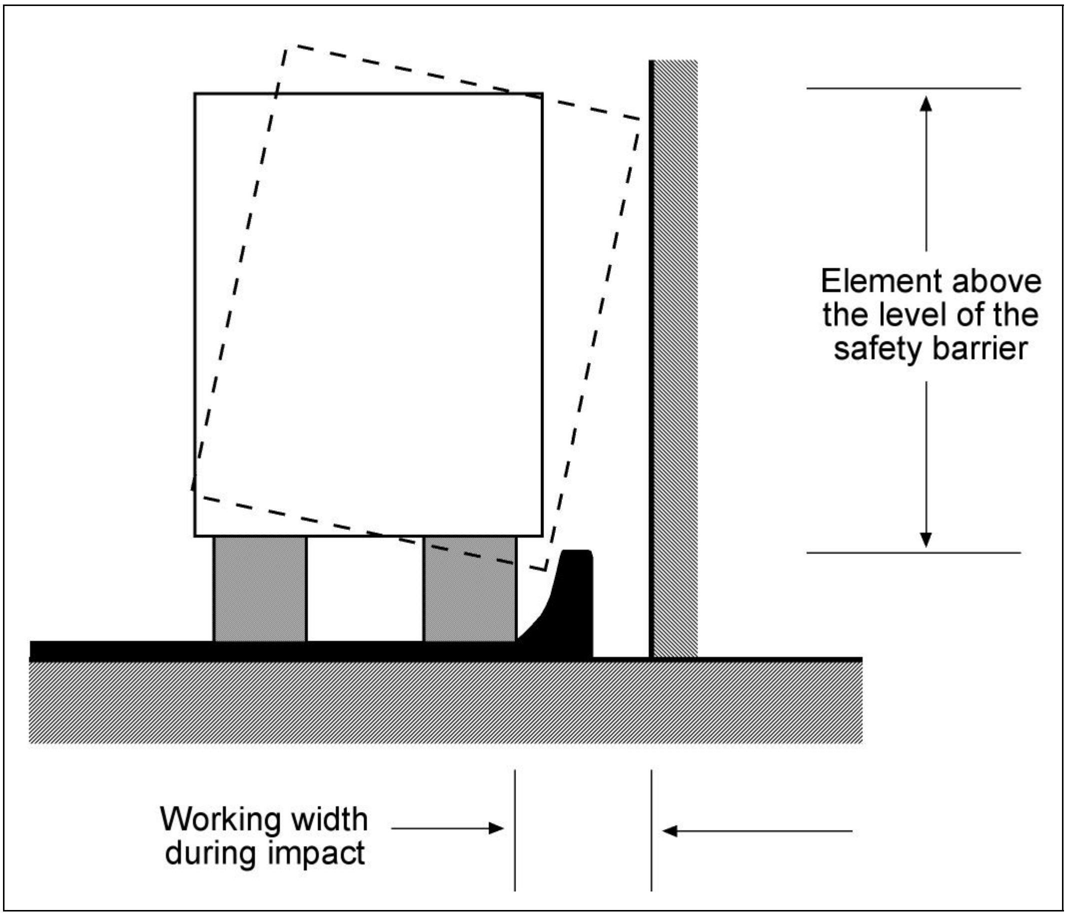
Dynamic deflection clearance.

Further detail refer to Table 4-6.

Further detail refer to Table 4-7.

It is also desirable to ensure that the distance between a rigid or semi-rigid barrier and the object is sufficient to prevent a high centre of gravity vehicle from snagging on the hazard should it impact the barrier and pivot about the roll axis of the vehicle. This is particularly important in the case of structural components such as bridge piers and gantry columns where secondary effects could be serious (e.g. structure collapses and falls onto roadway). To satisfy this requirement a desirable working width, measured from the face of the barrier to the face of the fixed object, should be provided.

The desirable working width measured from the face of the barrier to the face of the fixed object, is illustrated in Figure 4.4. Values for the working width are shown in Table 4.5. These values are based on the vehicle dynamics of a 4.3 m high van type rigid or articulated truck. The working width is dependent on the crossfall of the adjacent carriageway and the likely impact speed. The values in the Table 4.5 may be interpolated to account for a particular speed and crossfall.



(Source RTA 1996)

Figure 4.4 — Working Width for Concrete Barrier

Table 4.5 — Working Widths for Concrete Barrier

Speed Zone	Crossfall towards the barrier (m)		
	0%	3%	7%
High-Speed – 100 km/h	0.8	0.9	1.1
Low Speed – 60 km/h	0.5	0.6	0.8

Note: Source RTA 1996. For situations where the road slopes away from the barrier, the values for a 0% crossfall should be used.

The deflection of wire rope safety barrier (WRSB) also varies depending on post spacing and impact speed. Manufacturers or distributors for the particular product should be consulted regarding the appropriate deflections to be assumed for any given situation. This information can be used with that from other sources to determine the suitability of a wire rope safety barrier.

The results of tests reported by the FHWA and other testing authorities can be useful. For example, tests of various WRSBs indicate that the deflections under NCHRP 350 (1993) TL3 conditions (2000 kg vehicle, 100 km/h, impact angle 25°) may be of the order of magnitude shown in Table 4.6. However, practitioners should note that the systems tested to NCHRP 350 (1993) may be different to those available in Australia with different rope heights, post types and footing conditions. Reference should also be made to manufacturer's installation specifications and any information that is available from the relevant jurisdiction.

Table 4.6 — Approximate Deflection of Wire Rope Safety Barriers

Post Spacing (m)	Approximate Deflection (m)
1.0	1.5
2.0	2.0
2.5	2.5
3.0	2.7
5.0	3.4

Table 4.7 provides guidance on clearances that should desirably be provided to accommodate the deflections of semi-rigid systems for various speed environments and for single and nested beams. The values tabulated are based on computer simulation and field tests and are for a 2.0 m post spacing and rails that have a base metal thickness of 2.7 mm. It should be noted that some jurisdictions allow an absolute minimum clearance for W-Beam of 1 m with normal post spacing (2.0 m) and 0.5 m with a post spacing of 1 m.

Where an object is within the dynamic deflection of a semi-rigid barrier, the stiffness of the rail can be increased by reducing the post spacing and/or by using nested rails, with a consequent reduction in dynamic deflection.

It should be noted that the values in Table 4.7 assume adequate anchorage and soil strength. Compaction of the soil is of primary importance because any benefit realised by either strengthening technique (i.e. nested rail or reduced post spacing, or both) can be reduced or eliminated if the soil cannot provide the required resistance to lateral loads on impact. The designer should also be aware that a truck could lean over the barrier on impact, thus requiring a greater offset to prevent contact with a hazard.

Table 4.7 — Clearance for Semi-Rigid Barriers

Barrier Type	Post Spacing (m)	Dynamic Deflection (m)	Impact Conditions
W-Beam (G4) Refer Figure 4-1	2.0	1.0	2000 kg vehicle at 100 km/h and 25 degree impact angle
W-Beam (G4) (Back-to-back median application)	2.0	0.5	2000 kg vehicle at 100 km/h and 25 degree impact angle
Thrie-Beam (G9)	2.0	0.6	2000 kg vehicle at 100 km/h and 25 degree impact angle
Modified Thrie-Beam	2.0	1.0	8000 kg vehicle at 100 km/h and 15 degree impact angle

4.2.4 Site Conditions

The following site factors need to be assessed:

Road Geometry

Flexible 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 safety barriers be located as far as possible from the edge of the trafficked 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 m) from the edge of the through lane as the angle of impact for errant vehicles may increase with clearance. At increasing impact angles the profile becomes ineffective and injury severity increases.

When located adjacent to horizontal curves, safety barriers may need to be offset further from the edge of traffic lane so that they do not impede horizontal stopping sight distance (refer to Figure 9.5 of Austroads *Rural Road Design*, 2003).

Sufficient width should be provided between the 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 suitably paved to ensure optimum barrier performance, and consideration should be given to sealing the shoulder (Austroads *Rural Road Design*, 2003). The shoulder width should not exceed 3 m as a wider width could encourage some drivers to use the paved shoulder area as a through lane.

For offsets greater than 4 m, flexible or semi-rigid systems should be used.

When 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 needs to 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 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 as 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 on slopes steeper than 1 on 10. Where this cannot be achieved a flexible system may be satisfactory on a slope up to 1 on 6, however, the distributor/manufacturer should be consulted in these situations.

4.2.5 Compatibility

As a general practice road authorities use a limited number of different, proven 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.

4.2.6 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 (refer Chapter 2). 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 end treatment may also be a significant factor with respect to the cost of the system, depending on whether a 'gating' or 'non-gating' system is used.

4.2.7 Maintenance

Maintenance of barriers is covered in Chapter 9. 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.

Particular attention needs to be given to the maintenance issues where traffic volumes are high, as the need for frequent repairs not only increases costs but also exposes maintenance workers to risk and disrupts traffic. Rigid systems are generally not damaged during impact and therefore have low maintenance requirements and costs. For this reason rigid barriers may be selected for situations on urban freeways where maintenance workers are particularly vulnerable.

Wire rope systems are generally rendered ineffective near the area of impact. However, they can be relatively easy to repair even though a significant number of posts may be destroyed during impact. The combination of concrete ground sockets, slotted posts, and cables used in the WRSB enables any damage to be readily repaired. Also, the cable used in WRSB systems is usually not damaged during impact and has an expected life greater than 20 years.

It is important that barrier systems are repaired properly so that they perform as intended. Simple designs have the advantage that:

- it is easier to repair them properly
- maintenance workers are more readily provided with the knowledge required to properly effect repairs.

4.2.8 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 safety barriers, especially in recreational and tourist areas. Section 4.1.4 provides some information on aesthetic safety barriers.

It may be preferred for aesthetic reasons that a particular type of barrier is used consistently along a road or section of road.

4.2.9 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 accident reports.

4.2.10 Environmental Impact

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

- barriers that have a larger frontage area may contribute to a build up of drifting snow or sand, thereby affecting operation of the road
- the use of certain preservatives in some wooden barriers or barriers that have wooden components may be an issue
- some types of 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.

4.3 Limitations on the Use of Barrier Types

4.3.1 Rigid Barrier

Rigid barrier should generally not be used in situations where it is likely to result in impacts occurring at angles greater than or equal to 15°, 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.

There is no minimum length requirement for rigid barrier except the need to shield the hazard and to provide structural stability.

4.3.2 Semi-Rigid Barrier

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. However, the convex (plan view) when used on the inside of small radius curves can mitigate against the development of tension in the rail. This is usually only a problem for very small radii such as those on the corners of intersections (refer section 5.2.7) and is addressed by weakening of the rail.

Apart from the length of need, the minimum length of W-Beam that should be installed depends on the particular application and is determined by aggregation of the various components. For example, a combination of an attenuator, a short section of rail and a trailing terminal could result in an assembly of W-Beam about 16 m long (i.e. 7.6 + 4.0 + 4.0) for a 70 km/h speed environment. As a general guide, 30 m can be taken as the minimum length of barrier that should be installed.

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 sufficient distance behind it to ensure that impacting vehicles do not vault over the barrier (refer Section 5.2.6).

4.3.3 Flexible Barrier

The maximum lateral slope on which wire rope safety barrier should be installed is typically 1 on 10. 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. The requirement for a maximum lateral slope of 1 on 10 also applies to the area immediately behind the fence for a distance equal to the likely deflection of the fence under vehicle impact.

Careful consideration should be given to proposals to install WRSB systems on curves that have a horizontal radius less than 600 m because the required rope tension and height may not be maintained during or after an impact. However, designers are advised to consult with WRSB manufacturers where it is proposed to install WRSB on curves less than 600 m radius. It is also noted that a WRSB has been successfully tested (RTA) on a horizontal radius of 200 m.

WRSB systems should not be installed on sag vertical curves where the K value is less than 30. This is because 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. This, 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.

(*Note: The K value is the length of a vertical curve in metres divided by the change of grade expressed as a percentage).*

Flexible WRSB systems should not be installed so that they connect directly to any other barriers or bridge parapets. The deflection (refer Table 4.6) 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. However, flexible barriers may be installed in close proximity to semi-rigid barriers in accordance with Figure 7.1.

The minimum length of WRSB at full height should comply with the manufacturer's specifications (e.g. not less than 24m). 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 should be consulted when determining anchorage spacing.

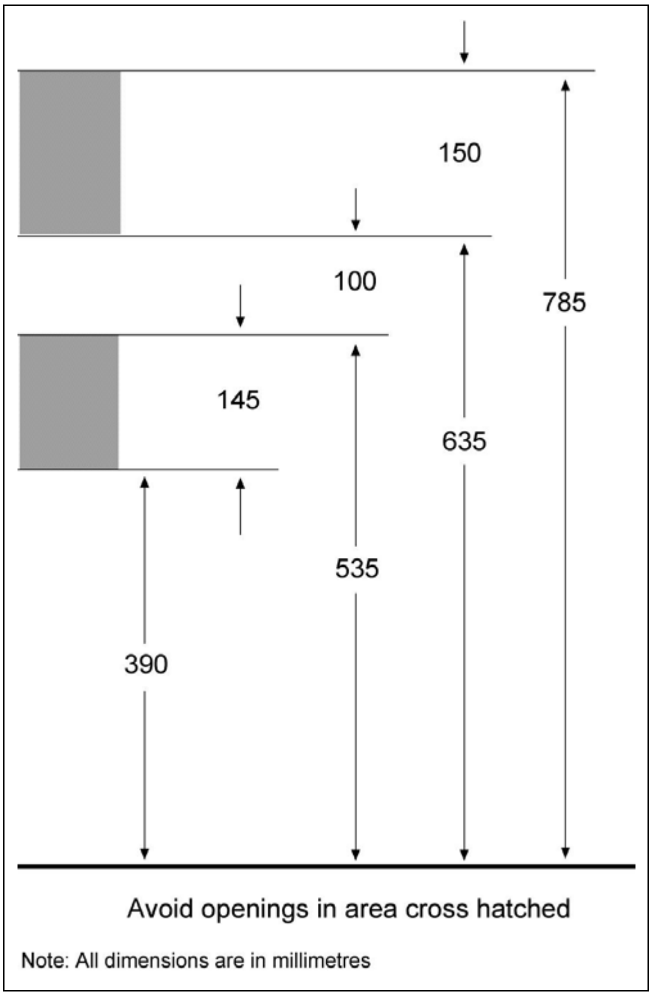
4.4 Barrier Height and Openings

The heights of the various barrier systems have been established after crash testing using appropriate test vehicles. The height of an installed proprietary system is therefore to comply with the requirements of the manufacturer. The heights of non-proprietary systems (W Beam and Thrie Beam) should comply with AS 3845:1999 (refer to Figures 4.1 and 4.2). Tolerances on the height apply with respect to installation. The recommended heights of the various barriers are shown in Figures 4.1 and 4.2.

For W-Beam, a height of approximately 710 mm (plus or minus 20 mm) to the top of the rail provides satisfactory protection against under ride and vaulting. The height of any semi-rigid system should not be allowed to fall below the tolerances as the system may not develop adequate torsional stiffness and vehicles may ramp over it. Ramping occurs at or below 600 mm heights. Successive pavement overlays or lift courses may reduce the relative height of barriers. The RTA of NSW uses "Abraham" blockouts with slotted bolt holes and an offset web to allow rails to be re-positioned at the correct heights after overlays are placed without having to reinstall posts.

The height is critical in that a rail installed too low will cause vehicles to pass over the top of (i.e. "vault") the barrier, whereas a rail that is too high will cause the vehicle to snag on posts and blockouts or even pass under the rail.

Openings in semi-rigid safety barriers should be avoided in the zones shown in Figure 4.5 unless the road safety barrier system complies with full scale crash testing in accordance with AS/NZS 3845:1999. The height of WRSB varies depending on the type of wire rope barrier system. It should also be noted that the configuration and height of cables used in the USA varies substantially from that used in Europe and Australia.



(Source AS/NZS3845:1999)

Figure 4.5 — Restrictions on Openings in Road Safety Barrier Systems

4.5 Effect of Pavement Slope

In general, safety barriers should be constructed vertically, however, if they are installed on a crossfall greater than I on 30 the performance of the barrier may be adversely affected, in which case they should be constructed at right angles to the pavement. Since most rigid barriers are designed to permit controlled vehicle climb on impact, it is most important that the vehicle impacts the barrier without initial vaulting induced by roadway features. This is best accomplished if the barrier is installed on a flat or only gently sloping surface (i.e.1 on 10).

Where rigid barriers are installed on superelevated curves, the preferred orientation is for the barrier on the high side of the curve to be installed with its axis perpendicular to the roadway, and for the barrier on the low side to be installed with its axis vertical (FHWA, 1997). This is shown in Figure 4.6. Barriers on the low side of the curve should not normally be installed with their axis perpendicular to the road surface because vehicle climb will be increased, as will the probability of vaulting.

As discussed in 4.1.3, rigid barriers can also be readily increased in height and strength to provide for a higher performance with respect to heavy vehicles. They are also readily adaptable to narrow medians between independently graded carriageways, an application that results in a much higher barrier on one carriageway due to the difference in level (refer Figure 4.7).

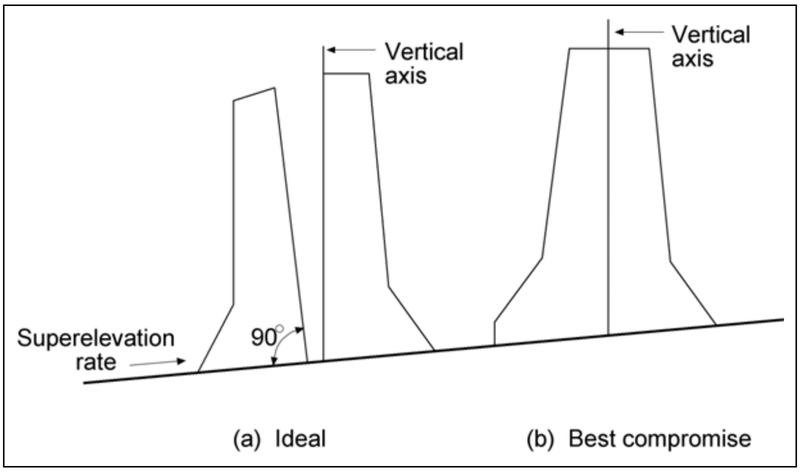
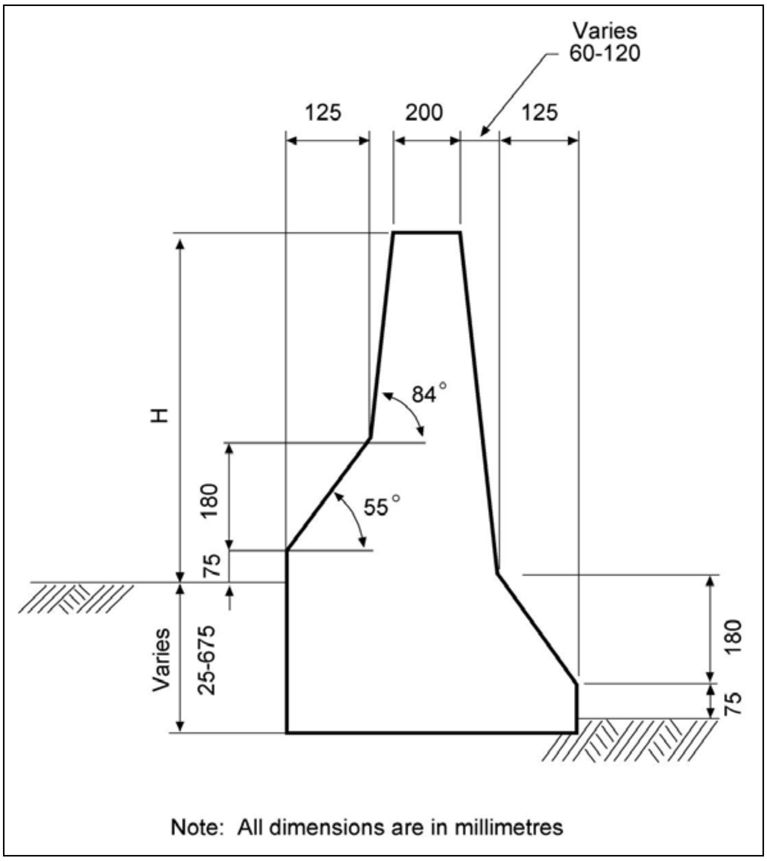


Figure 4.6 — Preferred Installation of Rigid Barrier on a Super-elevated Roadway



Notes:

1. H = 820 mm for TL3 and 1070 mm for TL5.
2. Foundation details are indicative only.

Figure 4.7 — Rigid Barrier in Narrow Median with Independently Graded Carriageways

5. DESIGN OF LONGITUDINAL BARRIERS

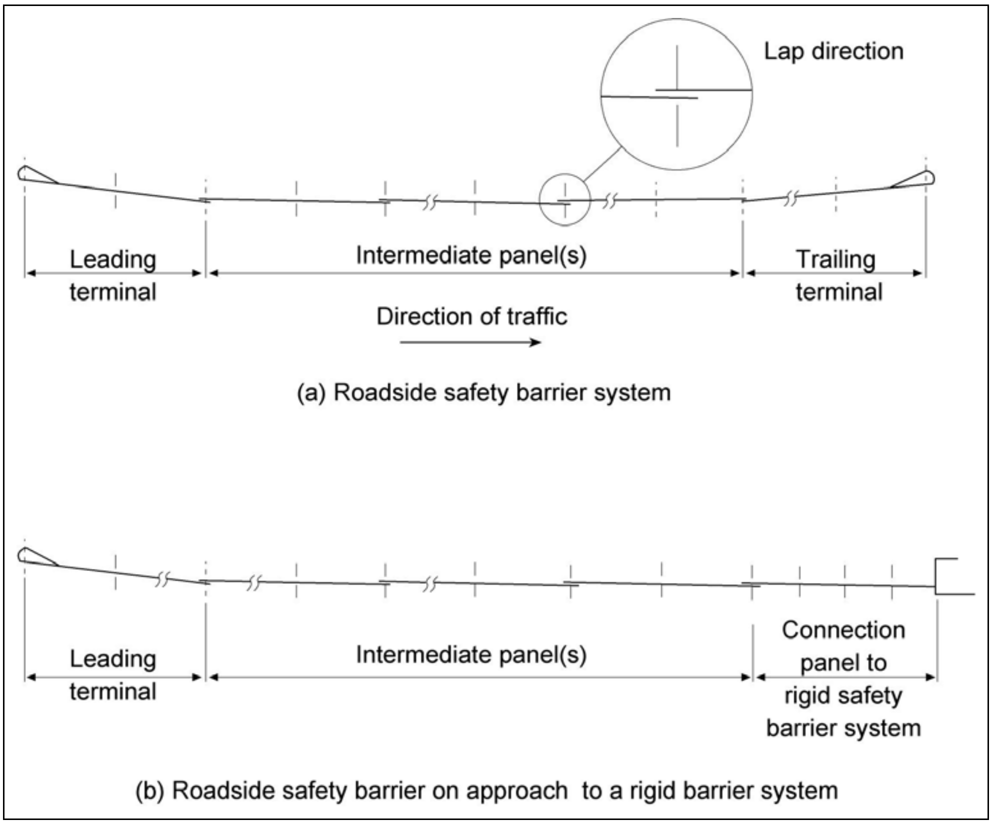
5.1 Introduction

This chapter provides guidance on the detailed design of barriers so that they shield motorists from roadside hazards and perform to the level intended. Guidance is provided for barriers situated on the edges of roads and within medians. Worked examples are shown in Appendix D.

The basic elements of a roadside barrier that need to be considered to achieve a satisfactory design are set out in Figure 5.1. While a semi-rigid barrier is illustrated similar elements apply to flexible and rigid systems.

At the commencement of the process, the following information should be available:

- a decision that the combination of hazard and risk at the site requires treatment;
- preliminary information on costs of options that relocate and/or modify the hazard, and the cost of options that mitigate the risk; and
- site data such as geometry, speed zoning, AADT, etc.



Notes:

1. The configuration in this figure is of a typical semi-rigid road safety barrier layout. Other systems will generally have the same basic elements, comprising end treatments (terminals), longitudinal barrier and connections (i.e. transitions) to other types of barrier.
2. The connection panel is commonly referred to as a transition section.

(Source: AS/NZS 3845:1999)

Figure 5.1 — Roadside Barrier Layout and Elements

The design process involves the selection of safety barrier systems that could be used and the development of details for the system such as:

- details of the transverse location of the barrier and any site modifications necessary to ensure that impact height criteria are met
- the point of commencement and termination
- accommodation of dynamic deflection
- treatment of leading and trailing terminals
- interface details where different types of safety barrier systems meet (e.g. a semi-rigid safety barrier joining to a rigid barrier)
- modifications to safety barrier at intersections or points of access to properties, etc.

When these details are available costs, benefits and other factors can be determined and compared for each option, and the preferred option selected.

5.2 Design Process

The process involved in the design of a roadside barrier system is shown in Figure 5.2 and comprises the following steps:

- gather further data
- select the design vehicle
- determine design speed, runout length or the design angle of departure
- determine the dynamic clearance available (refer Figure 4.3)
- determine lateral location
- determine leading and trailing points of need
- develop location details
- compare options
- adopt and implement.

The process may be applied to existing roads or new projects.

5.2.1 Step 1: Gather Further Data

At all locations where hazards have been identified it is important that sections of roads that have similar features are treated in a consistent manner. From site inspection and desk top studies the road should be divided into sections (minimum length of 5 km) where the geometry, land use, speed zoning and traffic volumes are similar. The following data should be obtained for each section:

- traffic volume and composition (cars, trucks, pedestrians, bicycles, etc.)
- 85th percentile speed of cars, rigid trucks, buses, and articulated vehicles
- detailed topographic information at sites selected for remedial treatment, such as embankment details, lateral widths of road, nature and location of hazards
- features of the sites that could pose difficulties such as public utilities, access to property, drainage, and site geology

- locations where restrictions to sight distance may occur and be critical (e.g. intersections, on the inside of a right hand curve)
- location, type and condition of existing barriers, if present.

Consistency of treatment along similar sections of road is the objective.

5.2.2 Step 2: Select the Design Vehicle

Historically, safety barrier systems have generally been designed to contain and redirect passenger cars. This has evolved because of the costs and other adverse implications (i.e. the practicality) of providing barriers, generally throughout the road system, that are able to contain and redirect trucks and buses in other than relatively low speed and shallow angle impacts.

The designer must determine the design vehicle to be adopted for barriers on any given section of road under consideration, the general categories being car/pickup truck, single unit truck/bus, van type semi-trailer, or tanker type semi trailer.

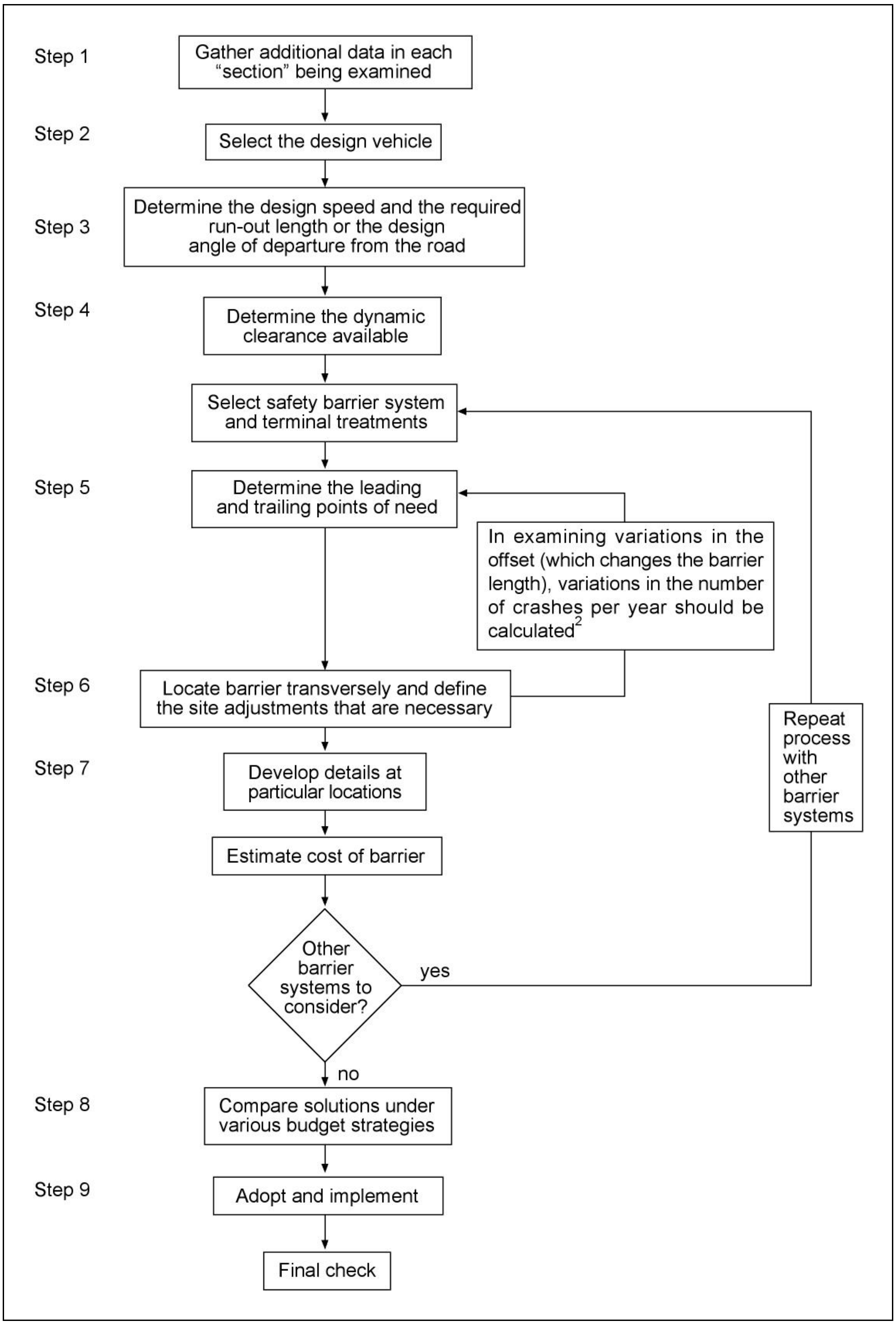
Safety barriers must meet the test level that is appropriate to the particular site conditions. Where impact speeds are higher than 70 km/h, safety barrier systems selected by designers should at least meet Test level 3 (TL3). Where a designer is certain that impact speed will not exceed 70 km/h, a barrier meeting TL2 may be considered. In addition, standard height concrete barriers and Thrie-Beam safety barriers that have passed TL4 tests and taller concrete barriers (at a height of 1070 mm) that have passed TL5 may be used where a higher level of containment is justified.

Except for barriers associated with bridges (refer to AS 5100:2004), and other situations where the consequences of vehicles leaving the road are extreme, safety barriers are not normally designed to contain van or tanker type semi-trailers (TL5 and TL6). This design limitation has been practised because of the relatively low volumes of these vehicles on many roads and the high cost of providing barriers to contain them. Where the risk is particularly high, a barrier meeting TL5 or TL6 may be considered. Situations that may warrant a higher performance level include:

- sites where relatively sharp horizontal curves and down-grades exist on highly utilised truck routes
- other locations with poor road geometry, for example, sharp curves on mountainous routes that carry substantial volumes of commercial vehicles
- high approach embankments to important structures in areas with high traffic volumes and high speeds
- pedestrian overpasses or other bridges where trucks impacting with piers could cause the structure to collapse
- situations where barrier penetration could have serious or catastrophic outcomes (e.g. a school or playground is located beside the road).

AS/NZS 3845:1999 advises that, in deciding the level of containment and type of barrier required for a given site, a designer should undertake a risk assessment (refer Chapter 2) and should also consider factors such as the:

- likelihood of higher impact angles
- presence of a relatively high percentage of heavier or faster vehicles in the traffic stream
- special needs of pedal cyclists and motorcyclists.



Notes:

1. Based on RTA (1996)
2. For calculation of number of crashes per year refer to Appendix A.

Figure 5.2 — Roadside Barrier Layout and Elements

5.2.3 Step 3: Determine the Design Speed, Run-Out Length or the Design Angle of Departure from the Road.

The choice of design speed for safety barriers should be consistent with Austroads Rural Road Design (2003) and Austroads Urban Road Design (2002a). For rural roads the design speed of every element of a road should either be equal to, or greater than, the 85^{th} percentile operating speed on that element. For urban roads it is recommended that geometric design for cars should be based on operating speeds 10 km/h above the legal speed limit.

The pre-impact speed and the angle of impact with safety barrier has been simulated by various models. Research (RTA, 1996) shows that:

- high speeds tend to be associated with maximum impact angles of 20°, and that angles of impact tend to increase with distance from the traffic lane with this effect being more pronounced at low speeds
- collisions with objects located relatively close to the lane occur at an average angle of between 10° and 20°, the 85^{th} percentile being about 22° and the 15^{th} percentile being between 2° and 5°
- the speed at impact varies according to road classification, with freeways and rural arterials having an 85^{th} percentile of about 90 km/h and urban arterials having an 85^{th} percentile of about 65 km/h.

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, a method based on 'run-out length' and an alternative method based on 'angle of departure'.

Run-out Length

Straight sections of road

This is the method favoured by many Australian road agencies and the American Association of State Highway and Transportation Officials (AASHTO, 2002). The "run-out length" (L_R) is the length of clear runout 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.

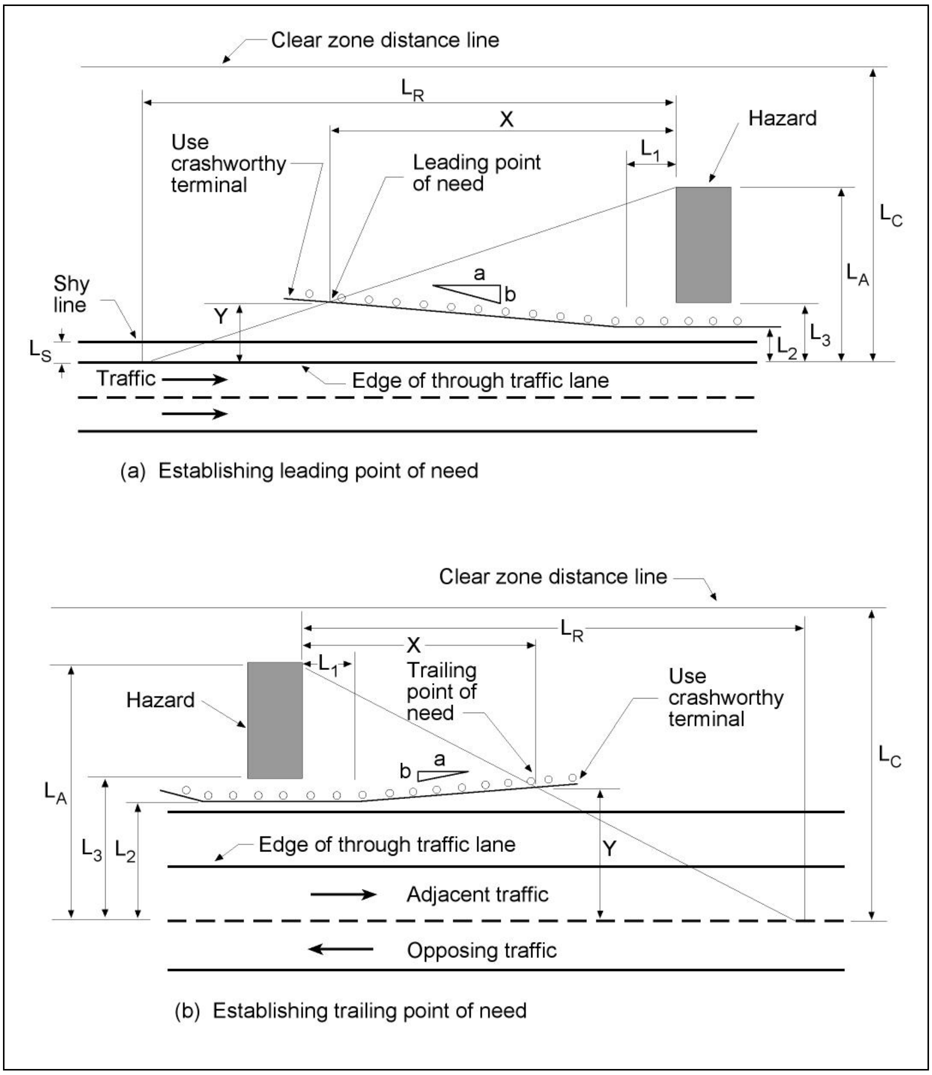
The application of the run-out length method to establish barrier "Length of Need" for both traffic approaching in the left lane, and for opposing traffic, is illustrated in Figure 5.3. On a two-lane two-way road, and for medians, these requirements are combined to develop a design layout that protects traffic from both directions. The layout of barriers on straight or nearly straight sections of road is established by applying the following formulae:

For installations where the barrier is flared (refer 5.2.7):

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

For parallel installations that have no flare:

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



Notes:

L1 is the tangent length of the barrier upstream from the area of concern.

L2 is the barrier's lateral distance from the edge of the running lane.

L3 denotes the distance from the edge of the traffic lane to the nearest point on the hazard.

LC is the clear zone distance.

Figure 5.3 — Run-out Length Method of Determining Length of Need

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

$$Y = L_A - \left[\frac{L_A}{(L_R)(X)} \right]$$

Where:

X	=	the required Length of Need in advance of the area of concern (hazard).
L_R	=	runout length (refer Table 5.1).
b/a	=	flare rate (Table 5.4).
LA	=	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 5.3. 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 5.3 (a) and (b).

Table 5.1 — Run-out Lengths for Barrier Design

Design Speed (km/h)	Runout 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 lessen the lengths of barriers recommended on low-volume roads and streets. Some agencies consider these values to be excessive and have developed alternative methods such as the Angle of Departure method (AASHTO, 2002).

It should be noted that:

- The distance between edge of 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
- 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 indicating the contour lines
- L_A this 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, 2002) 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 [refer Figure 5.3(b)].

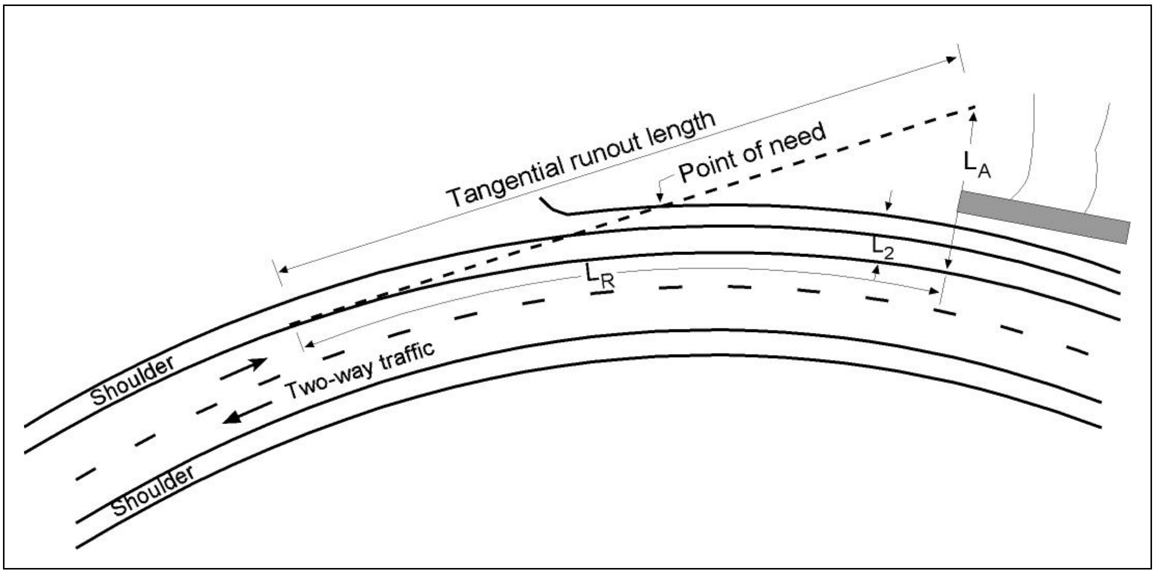
Three hazard location situations for an approach barrier length for opposing traffic have been identified by AASHTO (2002):

- If a barrier is beyond the appropriate clear zone, no additional barrier length and no crashworthy end treatments are required.
- If the barrier is within the appropriate clear zone but the area of concern (hazard) is beyond it, no additional barrier length is required but a crashworthy end treatment should be used.
- If the area of concern extends well beyond the appropriate clear zone (e.g. a river) the designer may choose to shield only that portion of it that lies within the clear zone by setting LA equal to LC.
- Length of Need should be rounded up to an even number of post spaces for flexible and semi-rigid barriers.

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 runout path. This will generally be the case 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. This is illustrated in Figure 5.4. If this distance, measured along the roadway, is shorter than L_R, it should be used to determine the appropriate length of barrier to install. If L_R is shorter, as might be the case on a flat curve, the runout length (L_R) should be used to determine the length of barrier.

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 2002). 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.



Note: In the case depicted, both the end wall and creek are hazards

Figure 5.4 — Length of Need on Outside of Curve using Runout Length Method

For barrier designs on the inside of curves the length of need is based on the length of runout (L_R) projected from the edge of the traffic lane to the rear of the hazard (refer Figure 5.5). 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.

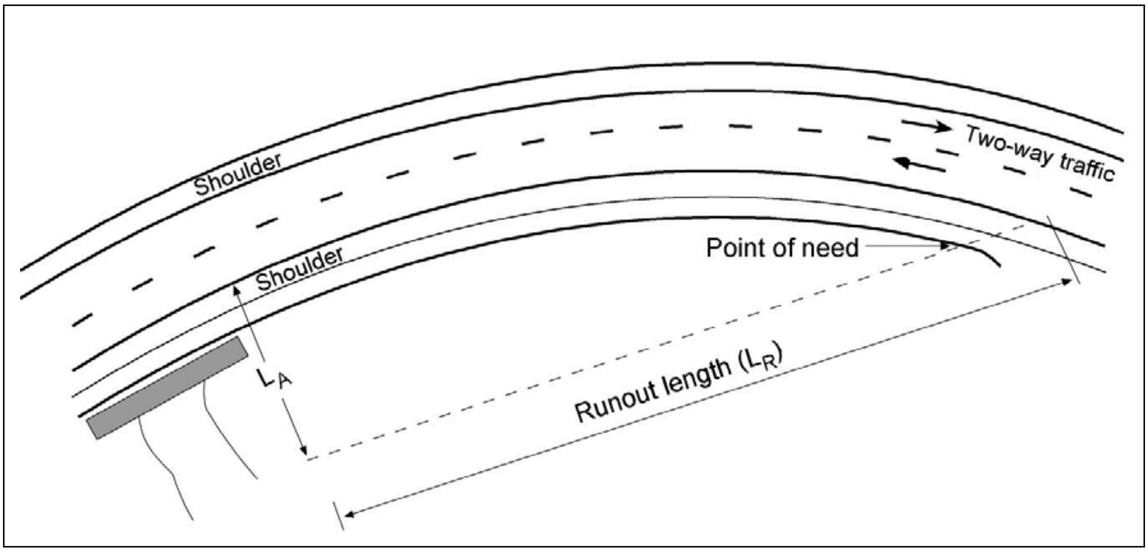
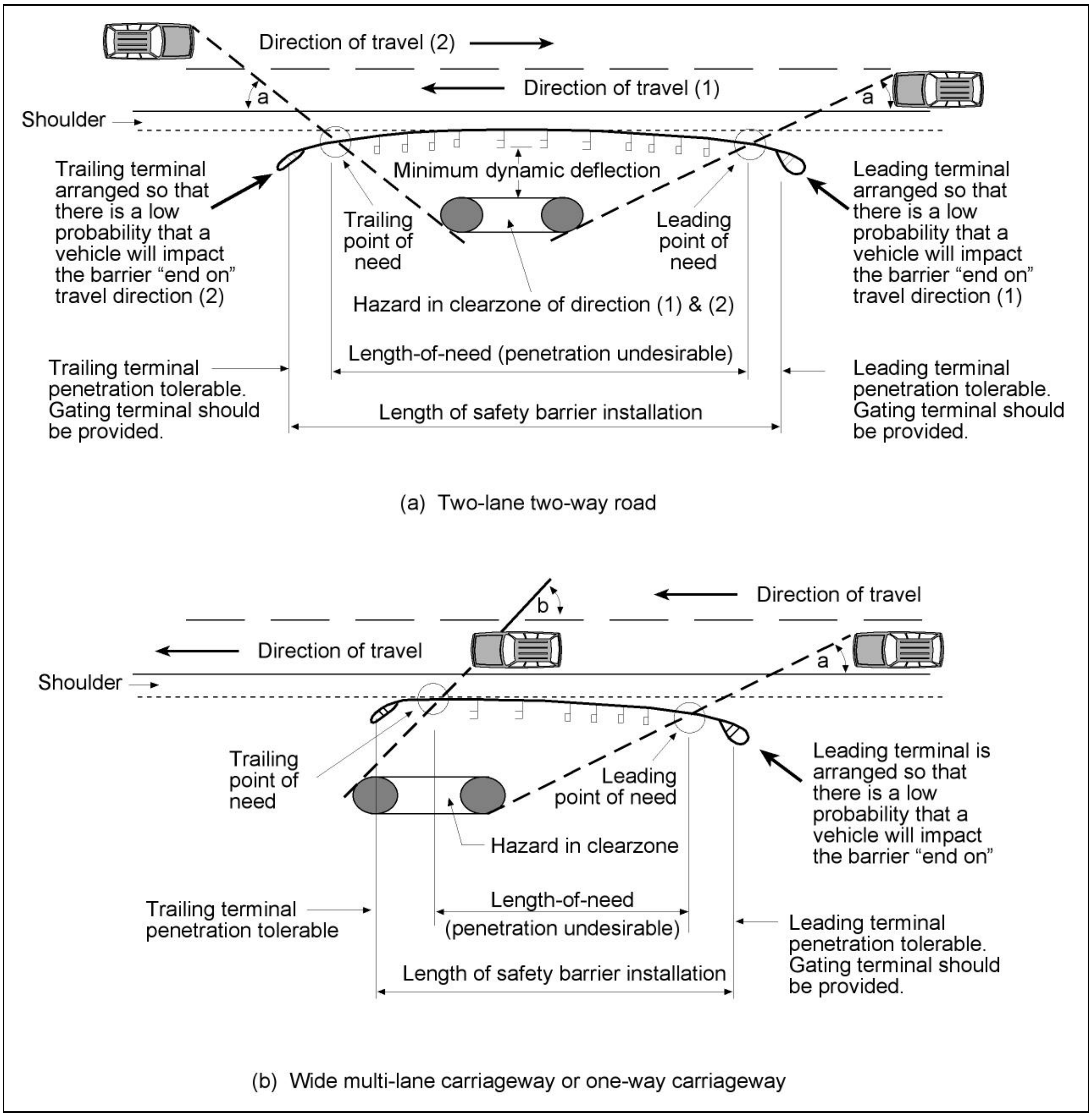


Figure 5.5 — Length of Need on Inside of Curve using Runout Length Method

Angle of Departure

Straight sections of road

This is an alternative method referred to in AASHTO 2002 and is the method preferred by some road authorities. The angle of departure of vehicles leaving the road varies over a range as described previously. 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 5.6 and examples are provided in Appendix C. The angle of departure is related to the posted speed limit and values are shown in Table 5.2.



(Source: RTA 1996)

Figure 5.6 — Angle of Departure Method of Determining Length of Need

Table 5.2 — Angles of Departure from the Road

(Source: RTA 1996)

Signposted Speed Limit	15th percentile angle (1:X)	85th percentile angle (1:X)

(km/h)	Use as leading angle (*"a"*)	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)

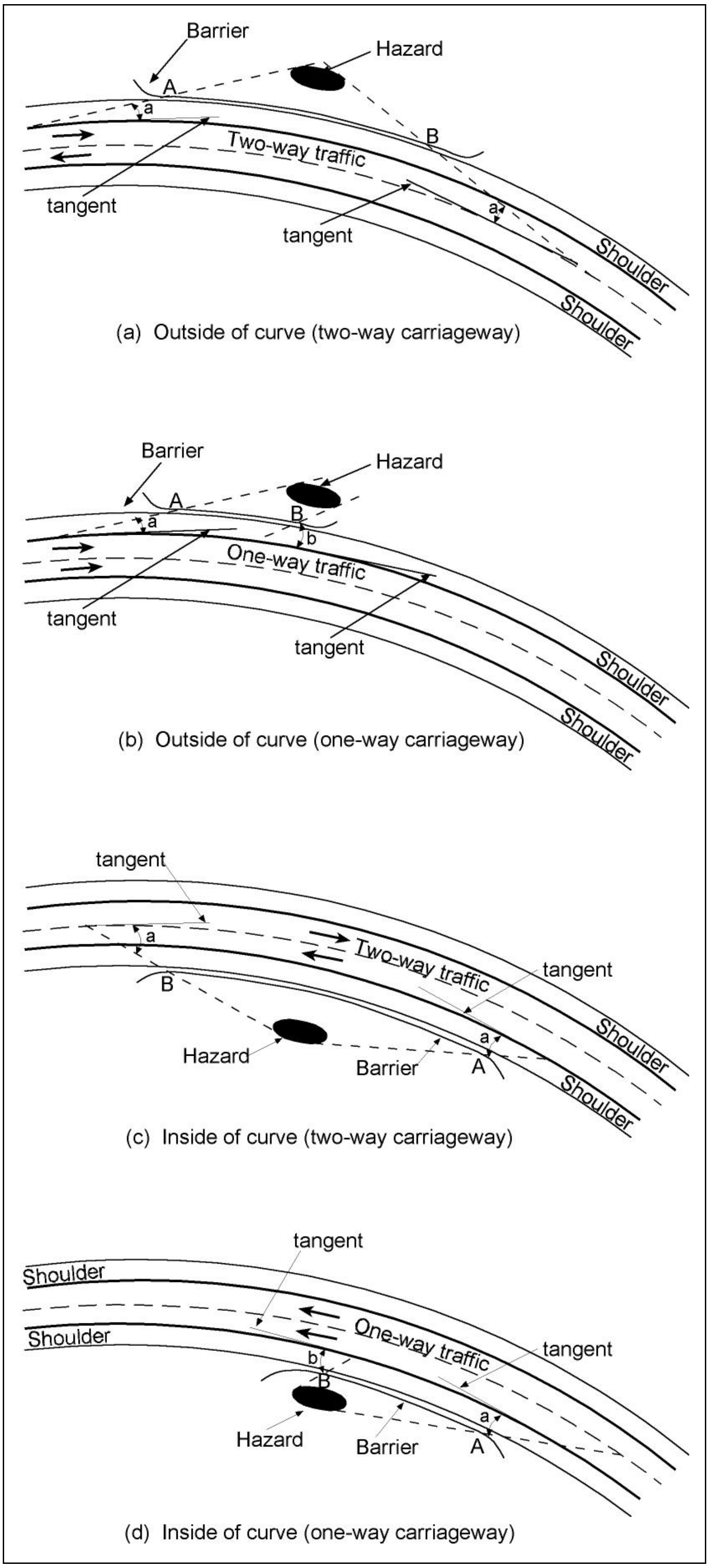
Curved sections of road

When determining the leading point of need for a 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 travel lane.

For a curve, the leading angle of departure from Table 5.2 (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 5.7 (a) to (d) illustrates the situations for hazards on the outside and inside of a curve, and for two-way and one-way carriageways.

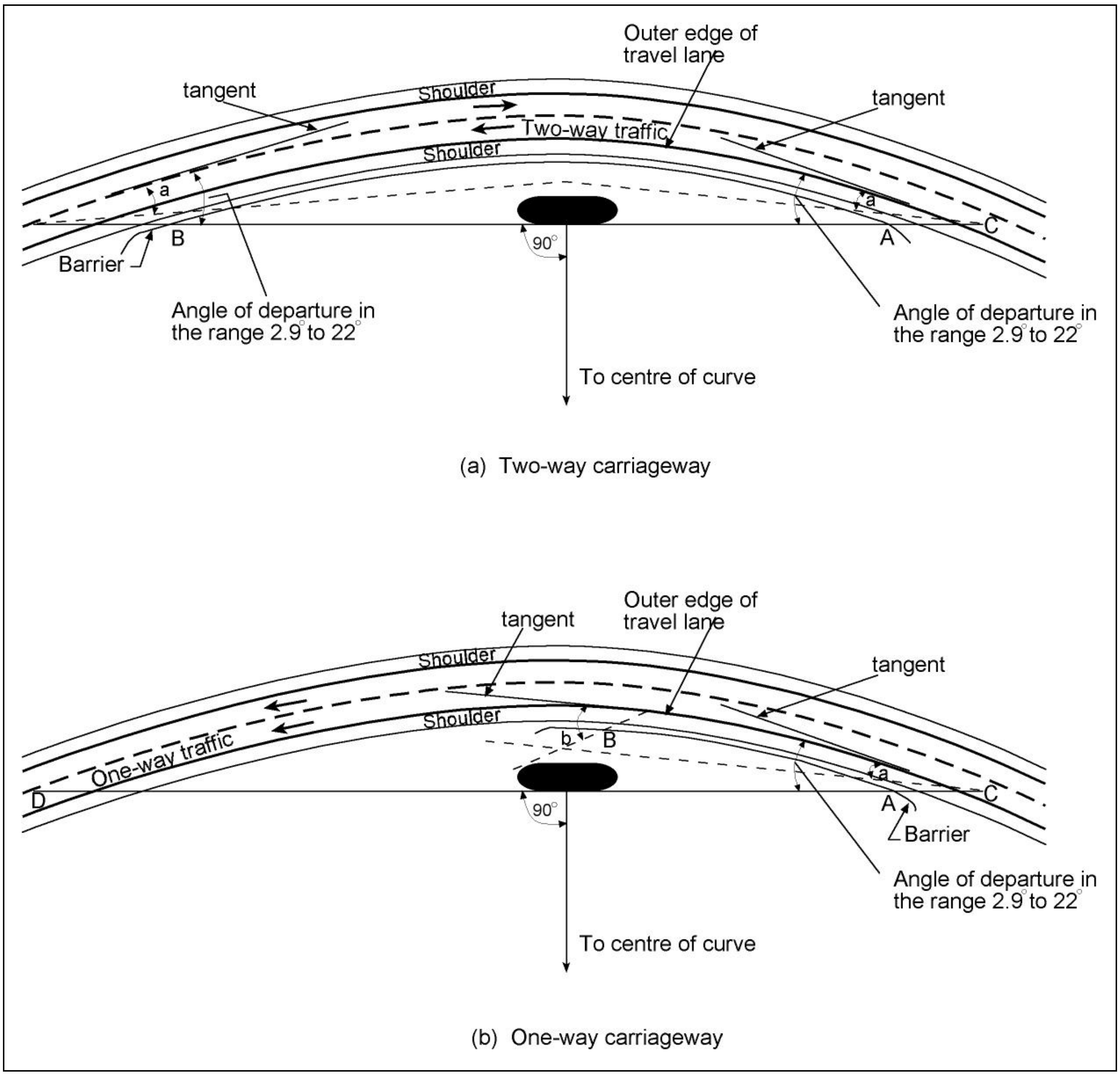
In determining the length of need for a safety barrier, there is a range of angles of departure that are considered between the leading angle of 2.9° (at 100 km/h) and the trailing angle of 22° (for all speeds). These are general limits and when applied in cases where the leading angle from Table 5.2 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 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 5.8 (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.



Note: A-B is the length of need

Figure 5.7 — Angle of Departure Method on Curves where Leading Angle Meets the Rear of Hazard



Notes:

1. A-B is the length of need
2. C-D is the chord across the rear of the hazard

Figure 5.8 — Angle of Departure Method where Leading Angle Does Not Meet the Rear of Hazard

5.2.4 Step 4: Determine the Dynamic Clearance Available

Safety barriers are broadly classified into the categories of rigid, semi-rigid and flexible and these categories exhibit different dynamic deflections during vehicle impacts (refer Chapter 4 and Figure 4.3). The dynamic deflection varies according to the impact speed, angle of impact and the characteristics of the barrier system. For deflection purposes, the angle of impact is taken to be 20^o – 25^o (close to the 85th percentile).

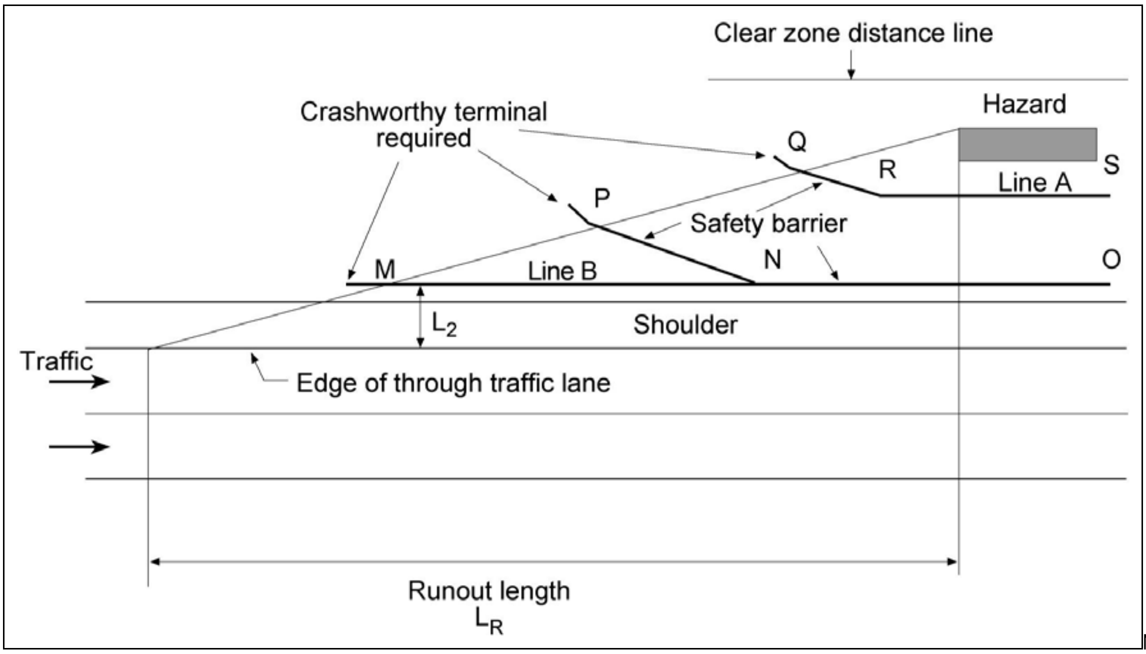
Table 4.7 provides a guide to the deflection to be allowed at various speeds for semi-rigid (steel beam) safety barriers. Deflections for flexible barriers (Wire Rope Safety Barrier) exceed the deflection of semi-rigid barriers (refer Table 4.6) and should be determined with reference to test results and manufacturer’s advice and specifications. Rigid (concrete) barriers are considered not to deflect at all.

As a general principle, the more flexible barrier should be used wherever it is able to be satisfactorily accommodated between the edge of the traffic lane and the hazard. The appropriate barrier can be chosen and located laterally between the edge of the traffic lane and the hazard in accordance with space available to accommodate the dynamic deflection and to meet other requirements that are described in Step 6.

5.2.5 Step 5: Determine the Leading and Trailing "Points of Need"

In Step 3 the Run-out Length method and the Angle of Departure method were described. Figure 5.2 shows how the Run-out Length method is applied to define the points of need while Figure 5.3 shows the application of the Angle of Departure method. The distance between the points of need is called the "Length of Need" and is the length of barrier (excluding the gating component of end treatments) required to shield an impacting vehicle from the hazard.

In situations where a hazard is located a significant distance from the edge of the traffic lane and the area between the lane and hazard is traversable it may be desirable to erect the barrier closer to the hazard and hence further from the road. Figure 5.9 illustrates how this approach can reduce the length of barrier required and hence the probability of the barrier being impacted by an errant vehicle. It also shows how placing the barrier on a flare reduces the length of barrier. However, it should be noted that a greater offset from the road could lead to more severe impacts with the barrier because of higher impact angles, and this needs to be considered by designers.



Notes:

1. Points M, P and Q are the initial points of need for a safety barrier system (i.e. gating terminal is to be added).
2. Points R-S and M-O represent the parallel sections of barrier on line A and line B respectively.

Figure 5.9 — Alternative Barrier Locations – Effect on Point of Need

5.2.6 Step 6: Determine Lateral Location

General

As a general principle, a semi-rigid or flexible safety barrier should be located as far from the traffic lanes as possible, provided that the intervening surface is traversable and has a slope no greater than 1 on 10. However, rigid barrier should be located no more than 4.0 m from the edge of the traffic lane because of the potential for higher impact angles and the relatively high severity of rigid barrier for impacting vehicles.

The lateral distance that a barrier is located from the edge of a road may be influenced by the:

- shoulder width required for the type of road
- distance from the edge of the traffic lane to the hazard
- Shy Line offset
- type of barrier chosen (deflection)
- presence of kerb
- embankment and cutting slope.

The Shy Line offset is the distance from the edge of the running lane beyond which a roadside object will not be perceived as a hazard that results in a motorist reducing speed or changing the vehicle position on the roadway.

Road Shoulder Width

It is usually preferable to provide the same shoulder width (if applicable) adjacent to barriers as is provided elsewhere along a road. Depending on future plans for the particular road, this may involve implementation of current design standards for shoulder width or provision of a shoulder that matches existing conditions. However, where a significant length of safety barrier is necessary the provision of a 3 m wide shoulder adjacent to the barrier may be considered. This would enable 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.

Consideration should be given to sealing the shoulder for its full width where safety barrier is installed at the edge of the shoulder (Austroads, 2003).

Distance from Traffic Lane to the Hazard

In situations where the space is severely restricted, it may be necessary to locate the barrier in an optimal position that may involve narrowing of the shoulder and choice of a barrier type/design that minimises deflection under impact.

In situations where the hazard is located within the clear zone, but a substantial distance from the road, it may be preferable to locate a flexible or semi rigid barrier as far from the edge of the traffic lane as is practicable. This should only be done if the area between the edge of the traffic lane and the barrier is a relatively flat and traversable surface (maximum slope 1:10) or is able to be constructed to this standard. The advantages of maximising the distance is that many errant vehicles recover within 5 m of the edge of the traffic lane and “nuisance hits” (i.e. impacts that do not result in injury but require expensive maintenance) are minimised.

Shy Line Offset

When roadside features such as bridge railings, parapets, retaining walls, fences or roadside 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, safety barriers should be located outside of the shy line, particularly where relatively short lengths of barrier are used.

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.

Design shy line offset distances for different speed environments are shown in Table 5.3.

In very restricted low speed situations, or where temporary barriers are erected for roadworks or special events, barriers may be located a minimal distance from the edge of the traffic lane, but preferably no less than 0.25 m.

Table 5.3 — Shy Line Offset Distances

Design Speed (km/h)	Shy Line Offset, L S (m)	
	Nearside (left)	Offside (right)
≤ or = 70	1.5	1.0
80	2.0	1.0
90	2.5	1.5
≥ or =100	3.0	2.0

Barrier Type and Deflection

As described previously, the choice of barrier type is important when considering lateral location because of the different deflection characteristics and foundation requirements that need consideration in relation to the distance that is available between the barrier and hazard.

When located on an embankment, posts must be able to transfer the loads resulting from the vehicle impact to the soil (refer 4.2.4). Flexible barriers and semi-rigid barriers have significant dynamic deflections and it is therefore necessary that the area behind these types of barrier has a slope no steeper than 1 on 10 for the width of the dynamic deflection. The slope beyond this area can be steeper.

Presence of Kerbs

Safety barrier tests are conducted with a smooth flat surface in front of the barrier and beneath the barrier. As a general principle, it is preferable that surface conditions at in front of and beneath barriers should be similar to the test conditions. While this is usually possible in rural areas there are instances where kerbs are required, and urban roads almost always have kerbs. This Section provides some guidance on the use of kerbs in conjunction with road safety barriers.

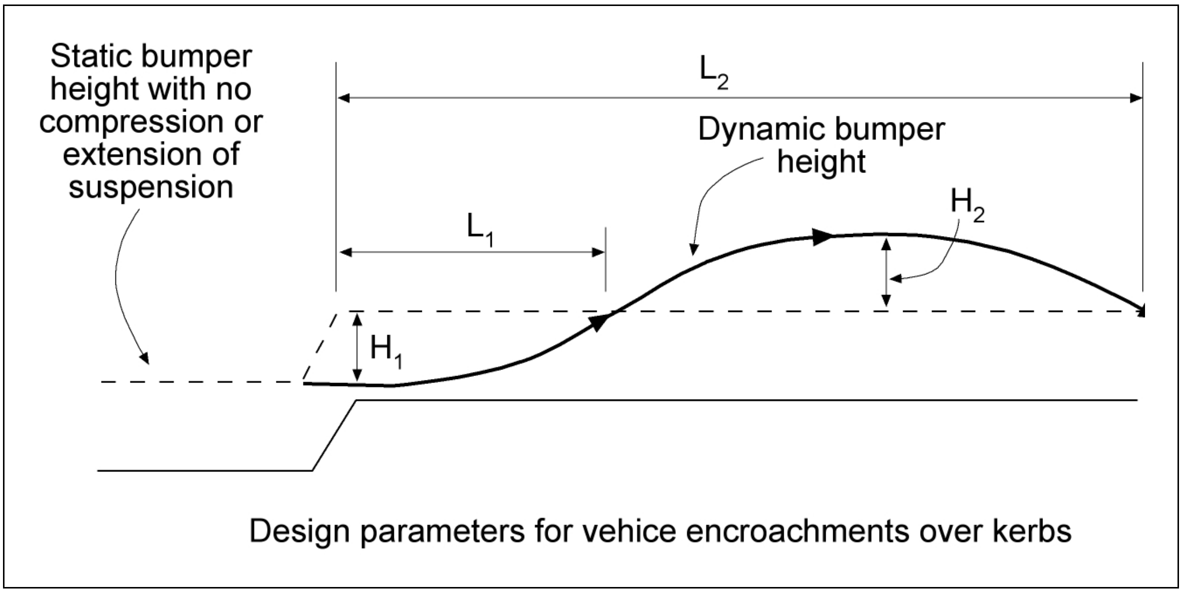
When a vehicle crosses a kerb at speed it will be subjected to an upward force such that pitch and roll will be developed. The combination of these effects will cause the vehicle bumper to follow a trajectory that will lead it to being higher or lower than its normal position relative to the wheels. This is shown diagrammatically in Figure 5.10. 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.

It can be seen from Figure 5.10 that when a vehicle impacts a kerb the bumper will be lower than the normal bumper position for a short distance and then rise higher than the normal bumper position for a significant lateral distance behind the kerb. An understanding of the vehicle behaviour (i.e. bumper trajectory) is important in locating the barrier. The lowering of the bumper may cause a vehicle to "snag" on the underside of the barrier rail within the distance L1 in Figure 5.10, while the rise of the bumper may cause it to "ramp" and vault over the rail. The 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.

The following guidance is recommended for the use of safety barriers in conjunction with kerb:

- Kerb should not be located in front of or under semi-rigid or flexible safety barriers on high speed roads; a drain located behind the barrier or a shallow gutter in front of the barrier are the preferred drainage solutions. Crash tests have shown that the use of any safety barrier/kerb combination where high-speed, high-angle impacts are likely should be discouraged. Where there are no feasible alternatives, AASHTO (2002) 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 barrier, drainage should be facilitated by the face of the barrier.
- Where a kerb must be used in conjunction with semi-rigid or flexible safety barrier, as is often the case in urban situations, it is desirable that it is placed either within the distance L_1 of the kerb or beyond distance L_2 shown in Figure 5.10, however, the latter location is usually impracticable. To ensure satisfactory barrier performance, it is preferred that the barrier is setback no more than 200 mm from the face of the barrier as shown in Figure 5.11 (300 mm in some jurisdictions). This offset 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 L_2) 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.

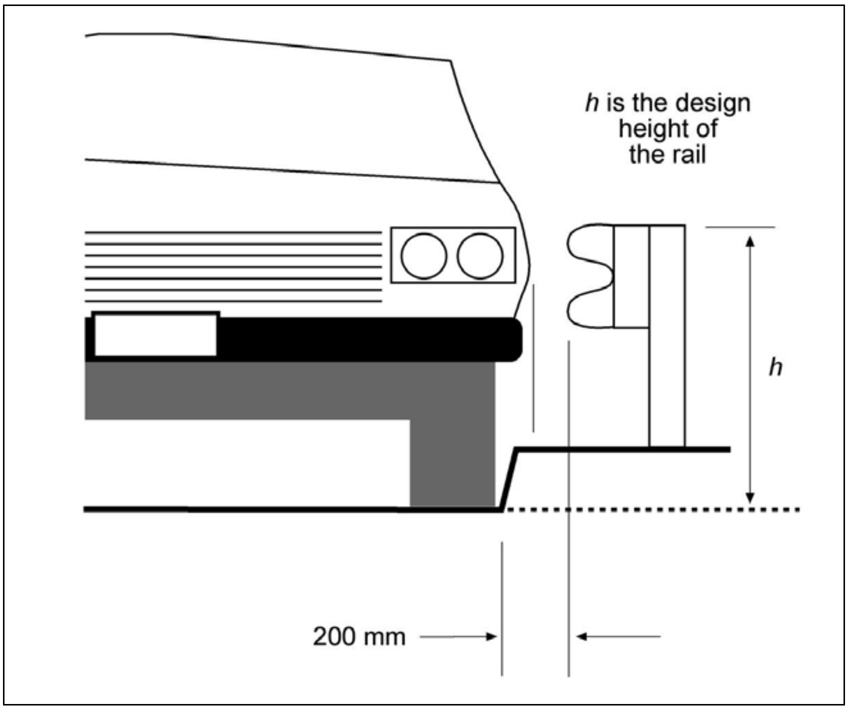


Note:

H_1 is the maximum depression of the vehicle bumper bar below its normal static height above the top of kerb.

H_2 is the maximum height of the bumper bar above its normal static height above the verge.

Figure 5.10 — Bumper Height Trajectory Characteristics over Kerbs



Source RTA, 1996

Figure 5.11 — Minimum Distance of Barrier Behind Kerb

Embankment and Cutting Slope

When vehicles pass over embankments, even at moderate speed, the bumper trajectory rises above normal bumper height, as illustrated in Figure 5.12, and this can also cause a vehicle to vault over an incorrectly placed safety barrier. The rise in bumper level is not significant for embankment slopes of 1 on 10 but becomes significant at greater slopes. 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 5.12, the point at which the bumper returns to its static height. This distance varies with design speed and batter slope (refer RTA, 1996). 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.

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 5.13. 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 barrier. A barrier should therefore not be located in the area defined by ‘L’ in Figure 5.13 (refer RTA, 1996).

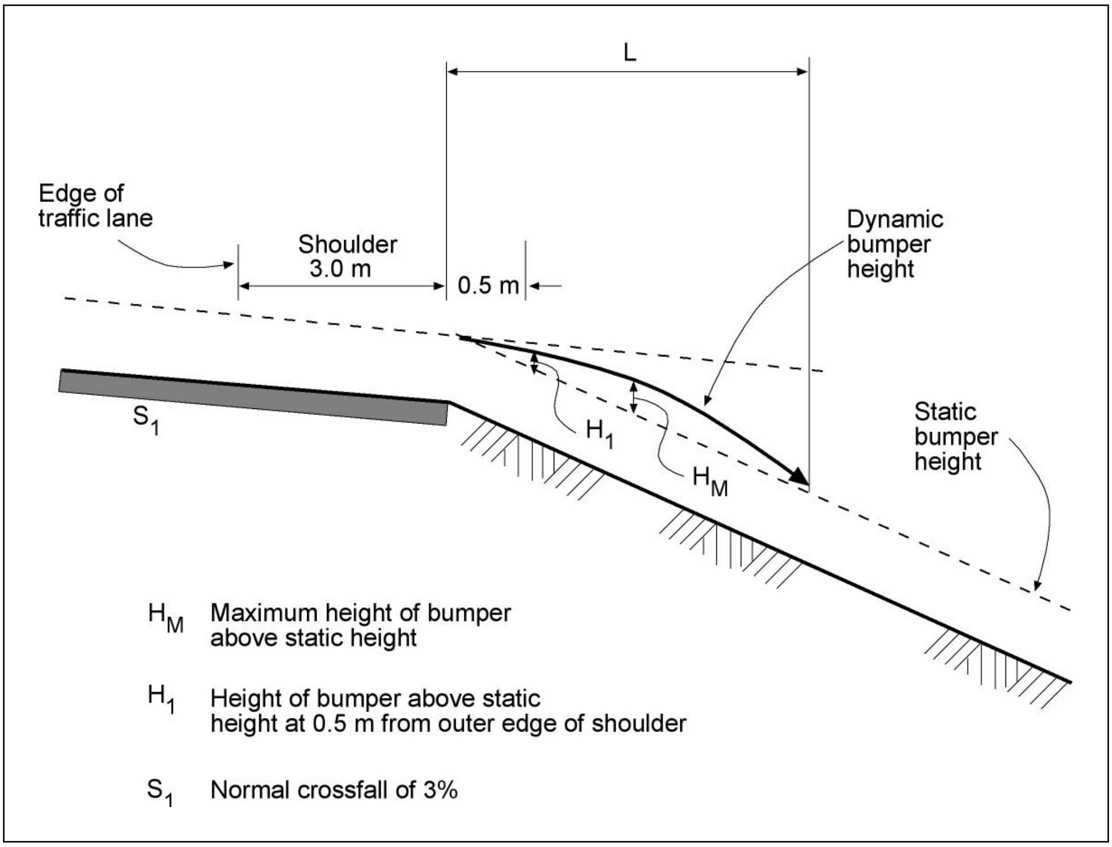


Figure 5.12 — Bumper Height Trajectory Characteristics Over Fill Embankments

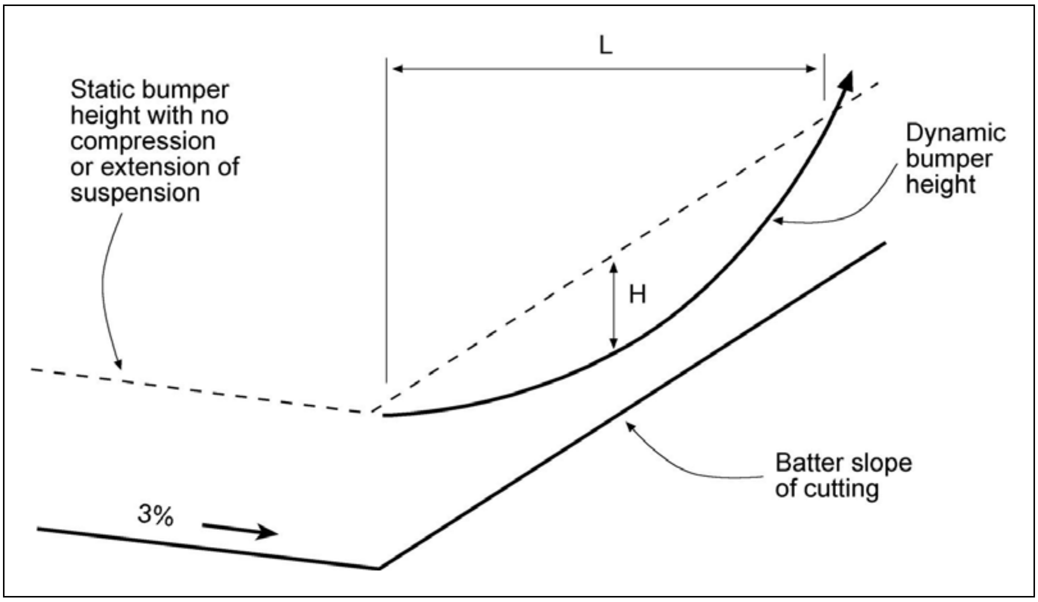


Figure 5.13 — Bumper Height Trajectory Characteristics Over Cutting Slopes

5.2.7 Step 7: Develop Location Details

Culverts

At culverts where posts can be supported by the embankment material, conventional steel systems can be used. Where it is necessary to have a semi-rigid barrier span a culvert, it may be necessary to fix the posts to the culvert. This is usually done by using posts with base plates and bolting them to a structurally designed strip footing or a part of the culvert that is designed to withstand the forces of a vehicle impact with the barrier. Alternatively, it is possible to have the barrier span small culverts by strengthening the barrier rail and providing an adequate foundation on both sides of the culvert.

Location of Median Barriers

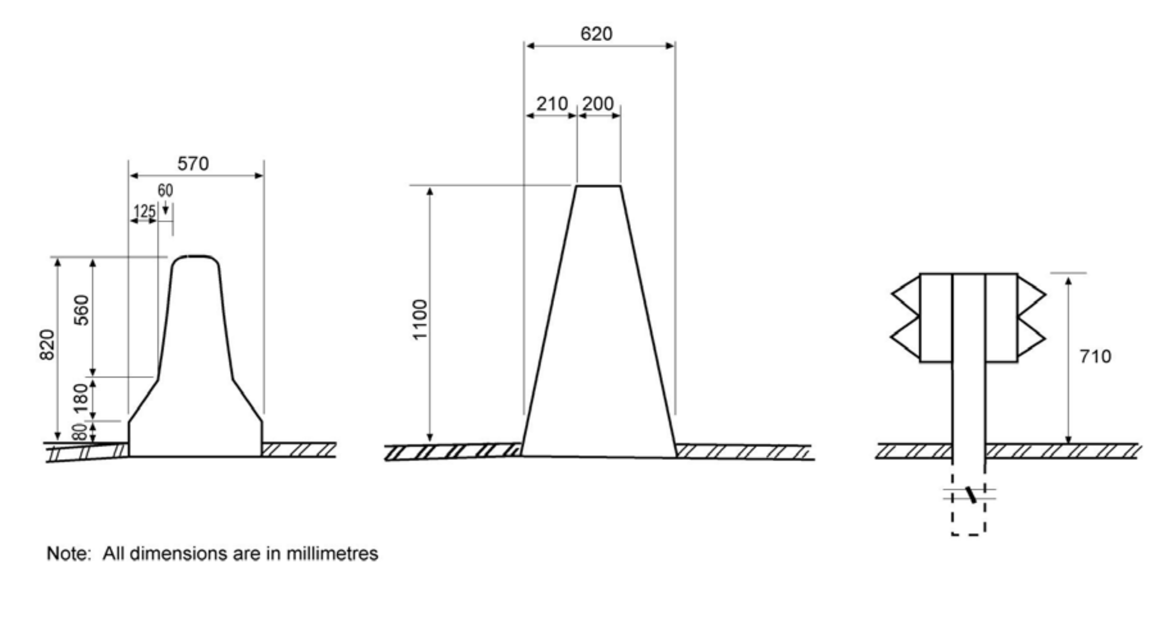
Median barriers are most commonly used to separate opposing traffic flows on divided roads. They may also be used along heavily travelled roadways to separate through traffic from local traffic, or to separate Transit Lanes (also called high occupancy vehicle (HOV) lanes) from general purpose traffic lanes.

Guidelines for assessing the need for a median barrier are provided in Chapter 2. The same principles that apply to the provision and installation of general longitudinal roadside barriers also apply to median barriers.

Median barriers are typically installed to shield motorists from:

- cross-median crashes
- space between twin structures over roads, railways or rivers
- lateral or longitudinal drainage structures in medians
- vegetation
- bridge columns or sign supports.

At many locations the space available is so limited that the most appropriate treatment is to provide a centrally located barrier, immediately behind the shoulder, capable of being impacted from either side. Rigid barriers are often chosen in these situations, however, back to back semi-rigid barrier or flexible barrier may be used where it can be located a sufficient distance behind the shoulder such that deflection on impact will not create an unacceptable risk for opposing traffic. Typical examples of median barriers in narrow medians are shown in Figure 5.14. 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).



F type	Single slope	Back to back W-Beam

Notes:

1. New Jersey barrier not shown as it is no longer installed, F Type is preferred
2. Tolerances (plus or minus 20mm) apply to heights of barriers

Figure 5.14 — Safety Barriers for Narrow Medians

Sloped Medians

The most desirable median is one that is relatively flat (slopes of 1 on 10 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 at least as wide as the clear zone (perhaps double depending on traffic volume) and such a width is often impracticable.

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 guidelines presented in Figure 5.15. In considering a specific length of median designers should assess the need for a barrier based batter slope or condition (section 2.6.1), median width (section 2.6.3), or drain profile (section 2.6.4).

Three basic median sections are presented in Figure 5.15:

- Type I - depressed medians or medians with an open drain.
- Type II - stepped medians or medians that separate carriageways with significant differences in elevation.
- Type III - raised medians (no kerb), or median berms.

The placement of barrier (wire rope, semi-rigid or rigid) in these medians is described below. 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 higher impact angles and resultant higher severity of impacts.

Type I

Illustrations 1 and 2 indicate barrier locations for shielding steep slopes (1 on 3 or steeper). For the situation described in Illustration 1, barriers may be required on both sides of the median adjacent to the shoulder. Illustration 2 relates to the situation where there is a steep batter on one side of the median and a flatter batter on the other. In this case single barrier may be placed on the high side of the median. Where slopes in the median are 1 on 10 or flatter a barrier may be located at or near the centre of the median as shown in Illustration 3. The deflection of the barrier used at this location should not be greater than half the median width.

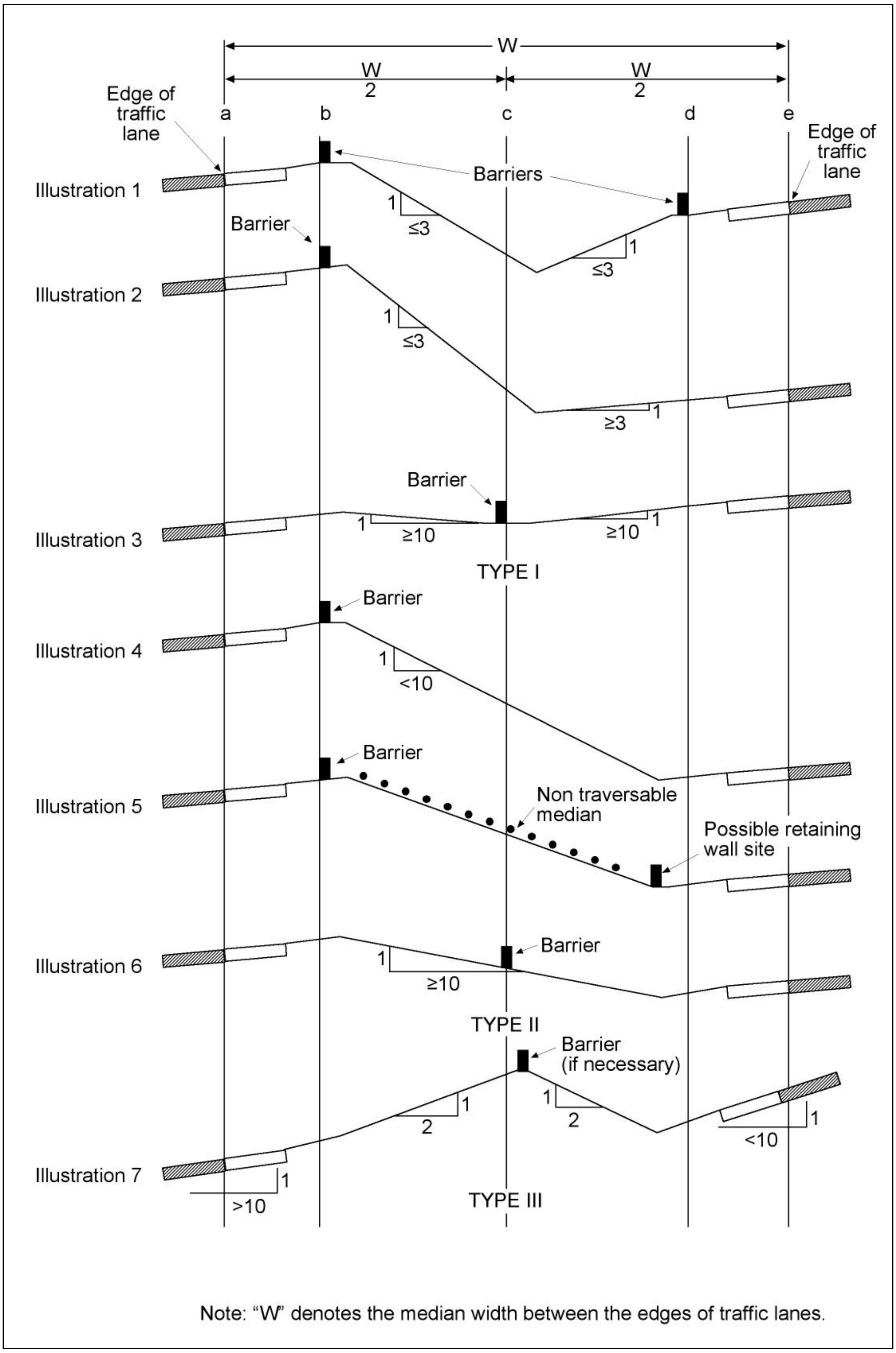
Type II

Where the slope of a stepped median is steeper than 1 on 10 (Illustration 4) and it is considered that a vehicle could run down a relatively flat batter and into the opposing carriageway, or possibly rollover over on a steep batter, a median barrier should be installed adjacent to the shoulder. For rough or infirm medians that are hazardous to errant vehicles (Illustration 5), barriers should be placed adjacent to both carriageway shoulders. 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 in the shape of an F-Type or single slope concrete barrier. In the case of very flat stepped medians it may be appropriate to locate a barrier in the centre of the median (Illustration 7).

Type III

Research has shown that if this cross section type is high enough and wide enough, vehicles may be redirected if the angle of impact is relatively shallow. To ascertain the dimensions of an earth mound that is high and steep enough to redirect an errant vehicle, the impact speed and mass of the impacting vehicle, and the angle of impact need to be carefully considered to confirm that an errant vehicle will not cross over the elevated median profile. If 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, a barrier should be placed near the shoulders of both carriageways. If retaining walls are used adjacent to each carriageway, it is recommended that the shape of the preferred standard concrete barrier be incorporated into the base of the wall. The most desirable median barrier placement is in the middle of a flat median.

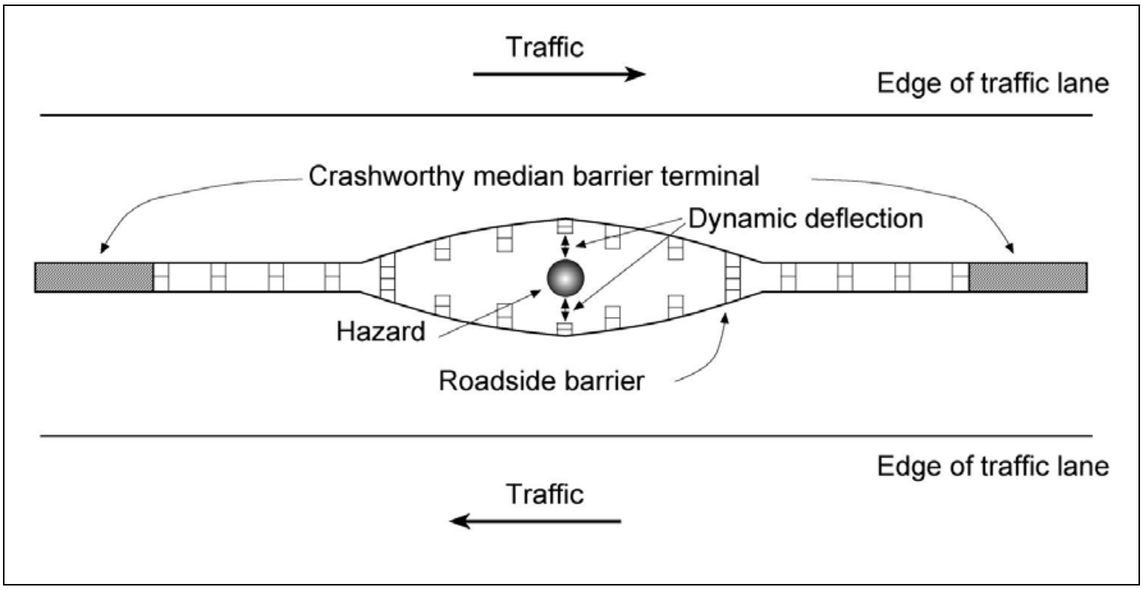


Note: "W" denotes the median width between the edges of traffic lanes.

(Source: RTA 1996)

Figure 5.15 — Recommended Barrier Placement in Wide Non-Level Medians

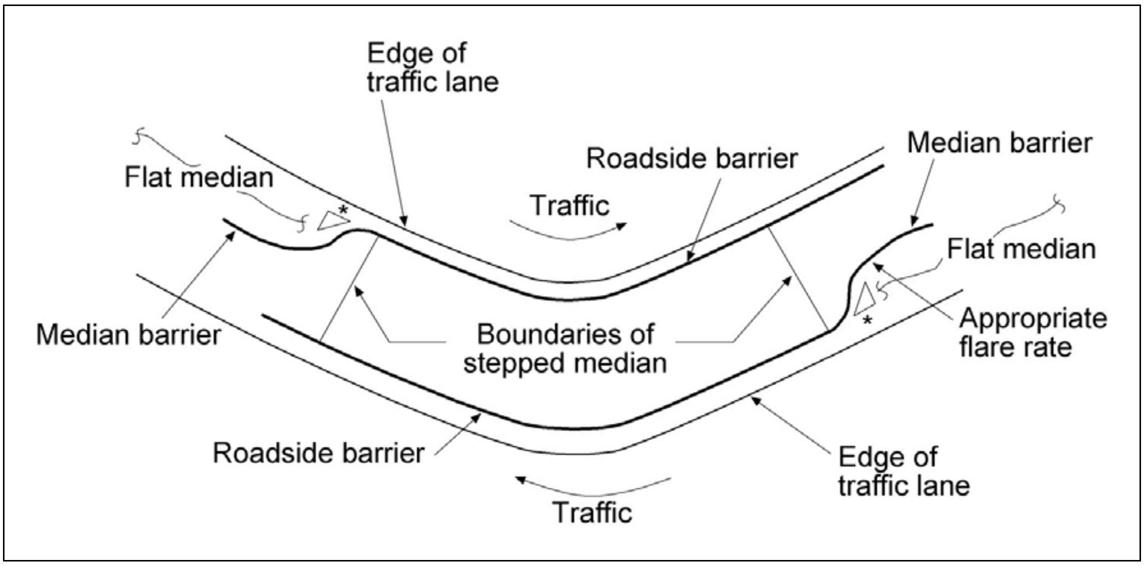
Figure 5.16 details how a rigid object such as a bridge pier can be shielded in a median. The treatment will differ depending on whether the barrier only shields an isolated object or whether it is to be incorporated into a longer barrier system. Where the median is wide enough, a flexible or semi- rigid barrier is preferred.



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

Figure 5.16 — A Layout for Shielding a Rigid Object in a Median

Figure 5.17 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. In this situation, the median barrier is “split”. Most median barriers can be split this way.



Note: For appropriate flare rates refer to Table 5.4

(Source: AASHTO 2002)

Figure 5.17 — Example of a Split Median Barrier Layout and Transition

Design Transitions

Where it is necessary to change from one type of barrier to another, or to physically join them together, the transition area must be detailed with care. Poor detailing of this interface or connection can result in poor performance in a crash. It is noted that only a semi-rigid steel safety barrier can be transitioned continuously with a rigid system. All other transitions can only be effected by the overlapping of differing systems. Transitions are discussed in Chapter 7.

Select Suitable End Treatment

Once the barrier has been located longitudinally (points of need) and laterally to accommodate dynamic deflection, suitable leading and trailing end treatments must be selected. End treatments can be either gating or non-gating, the characteristics of which are described in Chapter 8.

Anchorages

Flexible barriers require vertical release anchorages at the ends and, depending on the length of the barrier system, at intermediate points in conjunction with manufacturers' specifications. The anchorages enable the cables to release during reverse impact without snagging the errant vehicle or subjecting it to excessive ride-down accelerations.

Semi-rigid barriers do not require intermediate anchorages, but must have an anchorage at each end to enable tension to be developed in the steel beam so that it performs satisfactorily when impacted close to the end of the barrier system. The anchorage is provided by the end treatment.

Determine the Flare Rate

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. A flare consists of the leading or trailing end of barrier being located further from the road than the parallel length of barrier. They are used for general application of barriers and for transitions to barrier sections closer to the road shielding isolated objects such as bridge parapets. Flares have the advantage that they reduce the total length of barrier needed. However, installation of a flared safety barrier system may require additional earthworks to accommodate the flare and the terminal treatment.

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. This is illustrated in Figure 5.18. The flare rate adopted depends on whether the barrier is located within or beyond the Shy Line, and on the type of barrier. Suggested flare rates based on AS/NZS 3845:1999 are provided in Table 5-4.

These 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, 2002).

Flaring of barriers can have disadvantages such as:

- the greater the flare angle the higher the impact angle and the subsequent severity of crashes into 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 angle flares may also increase the need for additional earthworks and slope flattening in the area between the roadway and the barrier.

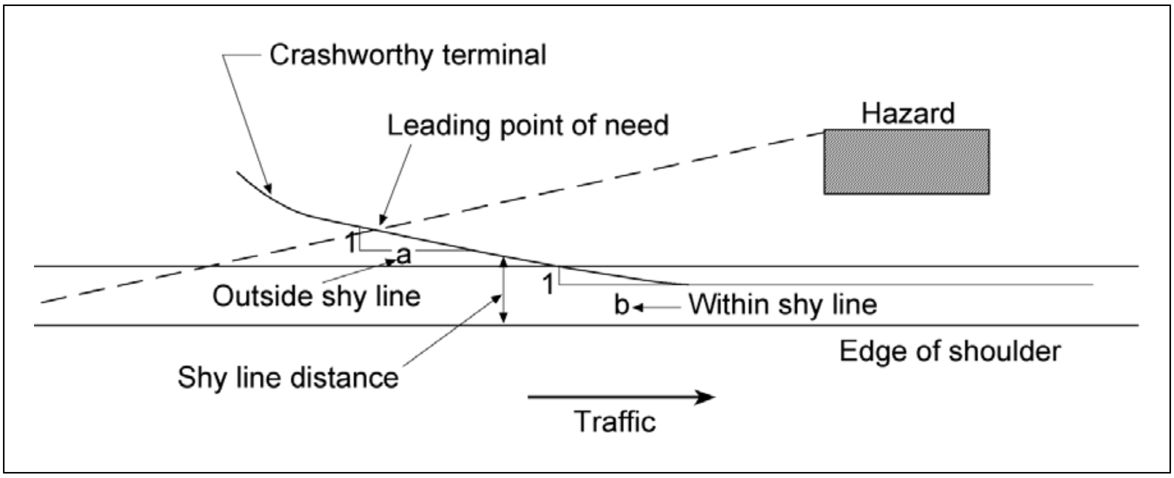


Figure 5.18 — Details of Flare Rate

Table 5.4 — Suggested Flare Rates (Source AS/NZS 3845-1999***)***

Design Speed (km/h)	Flare Rate for Barrier inside Shy Line (b:1)	Flare Rate for Barrier beyond Shy Line	
		Maximum flare rate for rigid barrier systems (a:1)	Maximum flare rate for non-rigid systems (a:1)
110	30:1	20:1	15:1
100	30:1	20:1	15:1
90	25:1	15:1	10:1
80	20:1	15:1	10:1
70	15:1	10:1	10:1
60	15:1	10:1	10:1
50	15:1	10:1	10:1

Access Through Barriers

Preferred practice is to avoid providing breaks in a safety barrier. However, it may be necessary to consider breaks at locations such as intersections, points of access to property, sites where pedestrians cross the road, and access points in medians.

At all of these sites other options which do not involve a break in the barrier must be considered. These would include the relocation of the entry/exit point, site works that remove the need for a safety barrier, and similar alternatives.

A treatment for use at intersections is described below.

Consideration should be given to the provision of emergency median crossings on access controlled roads for use by emergency vehicles. Auxiliary lanes or widened shoulders should be considered to allow emergency vehicles to safely leave and enter the traffic stream.

On wide medians access may be achieved by offsetting and overlapping the barriers. On narrow medians that have a rigid barrier, special “gates” incorporating a sliding or hinged steel profile may be used.

Sight distances to and from side roads or driveways, or through median openings, must not be obstructed by barriers.

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 the longitudinal barrier around the corner as shown in Figures 5.19 and 5.20. Where the intersection is located close to a bridge, a properly designed and installed transition treatment is required to connect the road safety barrier to the bridge barrier.

Intersections therefore present special problems for barrier design because, rather than impacting at acute angles typical of barriers adjacent to highway alignments, the impacts may be at any angle, including a right angle.

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.

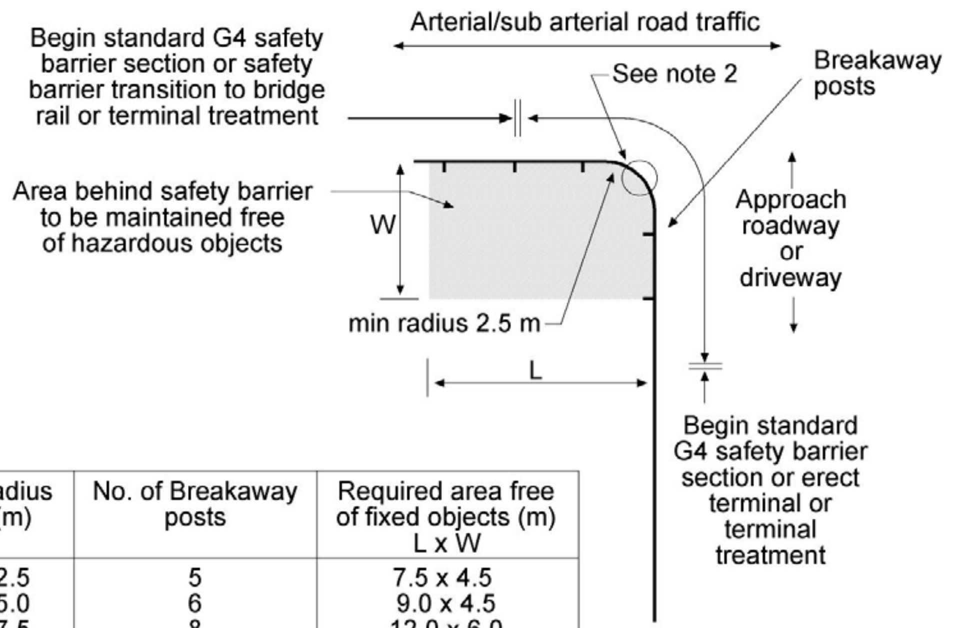
Intersection corners often accommodate road furniture such as signs, utility and signal poles and traffic control boxes, and any fixed hazards should be moved as far away from the traffic lane as practicable. The barrier systems that could be installed to shield these fixed objects may represent as much 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 accident, 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.

Conventional semi-rigid roadside barriers installed around the small corner radius have not been effective when the curved barriers have been impacted at high speed. Such impacts often result in vaulting or penetration of the barrier, or if contained, the vehicle and its occupants are subjected to high deceleration forces (FHWA, 1997). However, where a reasonably clear area can be provided immediately behind the barrier and a vehicle that penetrates the barrier will not endanger others, a weakened section of W-Beam is appropriate. Suitable designs are shown in Figures 5.19 and 5.20. The layout in Figure 5.19 applies where the radius is 2.5 m to 9.9 m and Figure 5.20 applies to radii 10 m or greater. The principle of the design is that the barrier forming the corner radius is weakened so that a design car impacting at a high angle is contained and decelerates at an acceptable rate of deceleration. A designated run-out area behind the barrier should be kept free of hazardous objects.

The weakening is achieved through the use of breakaway posts at 2.0 m spacings, by omitting blockouts, 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 substantially weakened, curved rail that has been shown to contain vehicles that impact at high angles. The requirements described above are noted in Figures 5.19 and 5.20, and are essential for safe operation of these curved sections.

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 hindered by barriers.

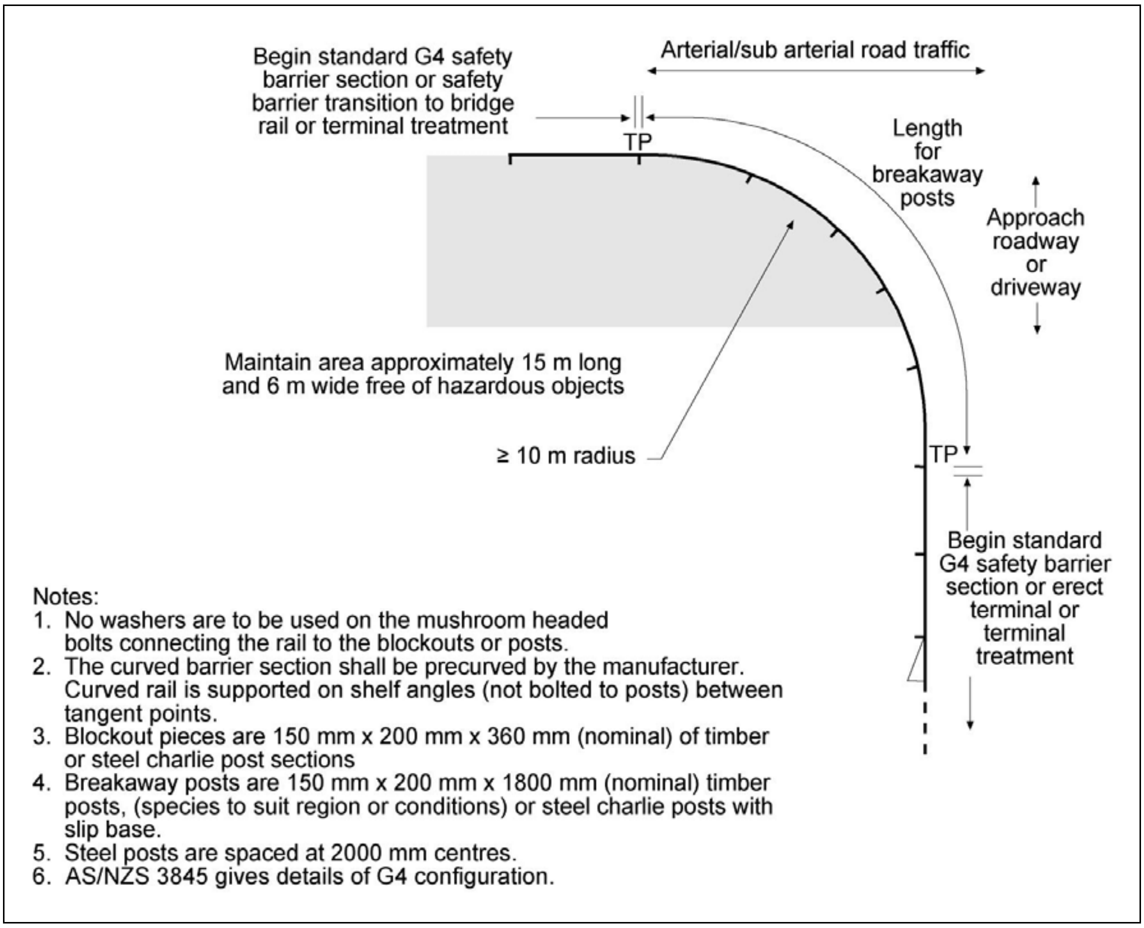


Radius (m)	No. of Breakaway posts	Required area free of fixed objects (m) L x W
2.5	5	7.5 x 4.5
5.0	6	9.0 x 4.5
7.5	8	12.0 x 6.0
10.0	11	15.0 x 6.0

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 5.19 — Curved Barrier Detail on a Main Road Intersection (Radius 2.5 to 9.9 metres)



(Source RTA 1996)

Figure 5.20 — Curved Barrier Detail on a Main Road Intersection (Radius 10 metres or Greater)

5.2.8 Step 8: Compare Options

Estimates of the cost of each safety barrier option should be prepared. Comparisons should be made between alternative barrier systems, and between the barrier options and options designed to reduce the hazard or change the risk. This comparison is done using conventional economic analysis techniques.

5.2.9 Step 9: Adopt and Implement

The appropriate option is then selected and incorporated into the design or road works program.