Guide to Road Design Part 4B

Roundabouts

Guide to Road Design Part 4B: Roundabouts

Austroads

Sydney 2023

Guide to Road Design Part 4B: Roundabouts

Edition 3.2 prepared by: Noel O'Callaghan, Madeleine Bekavac and Malcolm Mak

Edition 3.2 project manager: Albert Wong

Abstract

The Austroads *Guide to Road Design Part 4B: Roundabouts* provides road designers and other practitioners with guidance on the geometric design of roundabouts. It covers design principles and procedures, and guidelines for all the key elements, thus enabling practitioners to develop safe and efficient layouts. Part 4B also provides information on pedestrian and cyclist treatment at roundabouts and related topics such as pavement markings, signs and landscaping. However, designers should refer to other relevant parts of the Austroads *Guide to Road Design* and to the Austroads *Guide to Traffic Management Part 6: Intersections, Interchanges and Crossings Management* that cover traffic management and road use aspects of roundabouts and criteria for the appropriate selection and design of intersections.

Keywords

Design principles, design procedure, sight distance, geometric design, central island, entry geometry, circulating carriageway, superelevation, gradient, central island radius, pedestrians, cyclists, bicycle lanes, bicycle paths, shared paths, landscaping.

ISBN 978-1-925294-84-2

Pages 97

Austroads Project No. SRD6288

Austroads Publication No. AGRD04B-23

Edition 3.2 published May 2023

Edition 3.2 contains technical changes and editorial changes to sections 1.8, 3.2.4, 4.2, 4.6, 5.1, 5.2 5.3.3, 5.3.6, and 10.1. It also contains new guidance in Section 4.11.3 for mini roundabouts, Section 4.11.4 for radial roundabouts and Section 5.3.7 for cyclist and pedestrian priority at roundabouts.

Edition 3.1 published February 2021

Third edition published December 2015

Second edition published January 2011

First edition published August 2009

Publisher

Austroads Ltd.
Level 9, 570 George Street
Sydney NSW 2000 Australia

Phone: +61 2 8265 3300

austroads@austroads.com.au
www.austroads.com.au

About Austroads

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

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

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

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

- Transport for NSW
- Department of Transport and Planning Victoria
- Queensland Department of Transport and Main Roads
- Main Roads Western Australia
- Department for Infrastructure and Transport South Australia
- Department of State Growth Tasmania
- Department of Infrastructure, Planning and Logistics Northern Territory
- Transport Canberra and City Services Directorate, Australian Capital Territory
- Department of Infrastructure, Transport, Regional Development, Communications and the Arts
- Australian Local Government Association
- Waka Kotahi NZ Transport Agency.

Acknowledgements

The authors acknowledge the role and contribution of the Austroads Road Design Task Force Panel in providing guidance and information during the preparation of this Part, in particular, the project working group consisting of Albert Wong (Main Roads Western Australia), Bernard Worthington (Queensland Department of Transport and Main Roads) and Richard Fanning (Department of Transport and Planning Victoria).

Contents

Tables

Figures

1. Introduction

1.1 Purpose

The Austroads *Guide to Road Design* (AGRD) seeks to capture the contemporary road design practice of member organisations. In doing so, it provides valuable guidance to designers in the production of safe, economical and efficient road designs.

The Austroads *Guide to Road Design Part 4B: Roundabouts* (AGRD Part 4B) provides guidance to road designers on the geometric design of roundabouts, and together with three other parts:

- *Part 4: Intersections and Crossings: General* (AGRD Part 4) (Austroads 2023b)
- *Part 4A: Unsignalised and Signalised Intersections* (AGRD Part 4A) (Austroads 2023c)
- *Part 4C: Interchanges* (AGRD Part 4C) (Austroads 2023d).

provide guidance on the geometric design of intersections and crossings.

AGRD Part 4 covers intersection design principles that apply generally to intersections and crossings and the other three parts provide guidance specifically related to the type of intersection.

Figure 1.1 shows the eight guides that comprise the AGRD. Collectively these parts provide information on a range of disciplines including geometric design, drainage, roadside design, and geotechnical design, all of which may influence the location and design of intersections.

1.2 Scope of this Part

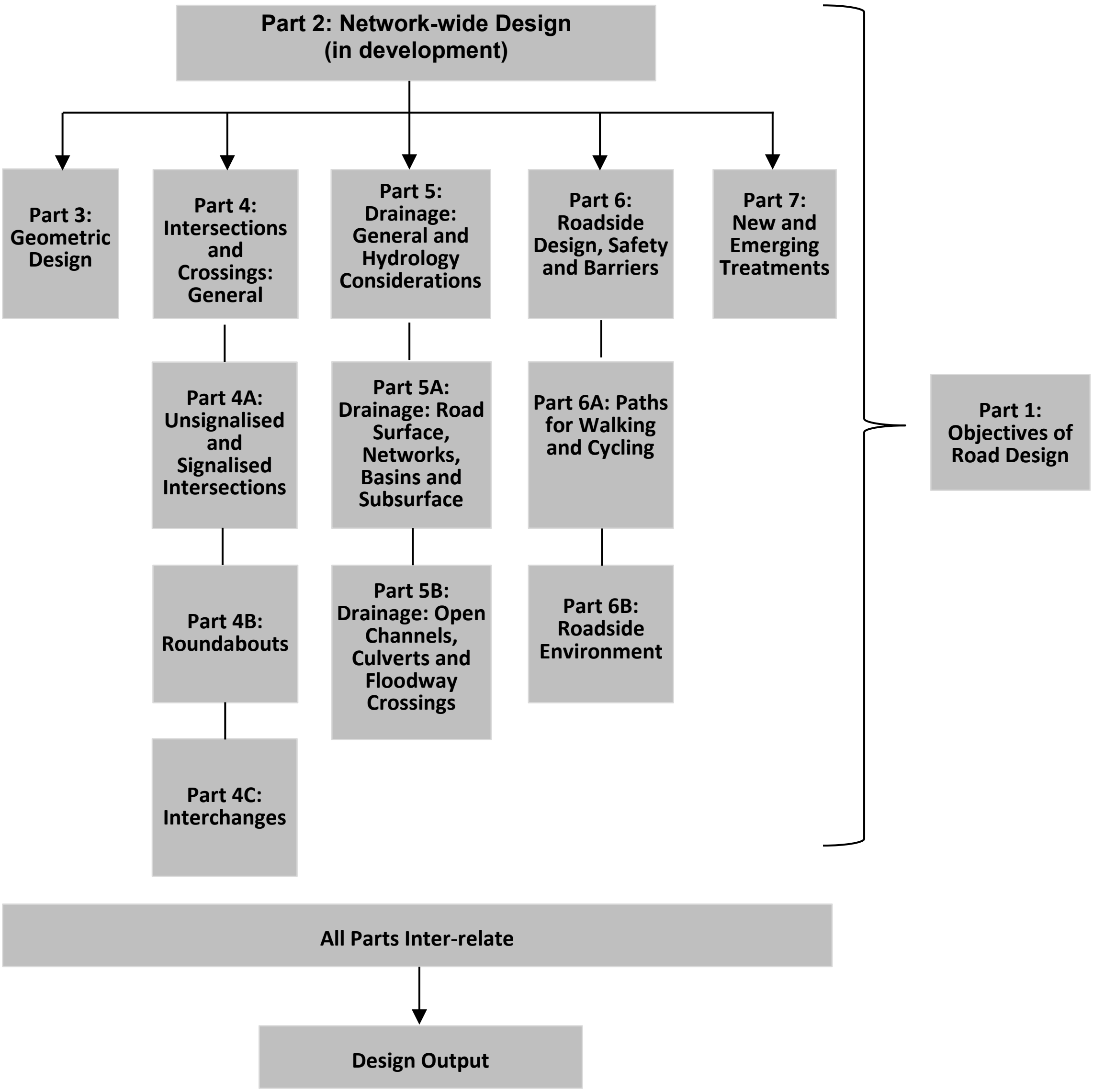
The purpose of this Guide in relation to roundabouts is to provide:

- a design procedure
- guidance on best practice for detailed design
- specific information relating to the accommodation of cyclists and pedestrians, landscaping, road marking and lighting.

The Guide focuses on the alignment, shapes and dimensions that should be applied in roundabout design to achieve a satisfactory outcome and is limited to the design of intersections. When used in conjunction with other relevant parts of the AGRD and the Austroads *Guide to Traffic Management Part 4: Network Management Strategies* (AGTM Part 4) (Austroads 2020), it provides the information and guidance necessary for a road designer to prepare detailed geometric design drawings that are adequate to facilitate the construction of roundabouts.

There are nine other subject areas spanning the range of Austroads publications that may also be relevant to the design of intersections.

Figure 1.1: Flow chart of the Guide to Road Design



1.3 Road Safety

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

The Safe System approach requires, in part:

- Roads and roadsides designed and maintained to reduce the risk of crashes occurring and to lessen the severity of injury if a crash does occur. Safe roads prevent unintended use through design and encourage safe behaviour by users.
- Provision of forgiving road environments that prevent serious injury or death when crashes occur.
- Align speed limits with the risk and function of the road and roadside environment (Australian Transport Council 2011).

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

Road designers should be aware of and, through the design process, actively support the philosophy and road safety objectives covered in the Austroads *Guide to Road Safety*. Further information on the Safe System principles can be found in the Austroads *Guide to Road Design Part 1: Objectives of Road Design* (AGRD Part 1) (Austroads 2021a).

1.4 Road Design Objectives

Road design objectives are discussed in Section 3.3 of AGRD Part 1, and the objectives also apply to the design of intersections and crossings, including roundabouts.

Section 3 of the Austroads *Guide to Road Design Part 4: Intersections and Crossings: General* (AGRD Part 4) (Austroads 2023b) discusses general design considerations for intersections, which also apply to the design of roundabouts.

1.5 Traffic Management at Roundabouts

As intersection design is influenced by traffic management considerations, road designers should be familiar with the traffic management considerations associated with roundabouts that are covered in Section 4 of the Austroads *Guide to Traffic Management Part 6: Intersections, Interchanges and Crossings Management* (AGTM Part 6) (Austroads 2020d). The use of roundabouts as a treatment, road space allocation, lane management and the traffic management aspects of functional design are covered.

An intersection (including roundabouts) should not be designed without consideration being given to existing and proposed traffic management requirements on the approaches. Designers should also refer to the Austroads *Guide to Traffic Management Part 5: Link Management* (AGTM Part 5) (Austroads 2020a) that covers mid-block traffic management and provides guidance on access management, road space allocation, lane management and speed limits.

Table 3.3 of the AGTM Part 6 summarises general issues relating to cyclists at intersections, and some of which relate to roundabouts.

1.6 Safety Performance of Roundabouts

A well-designed roundabout is the safest form of intersection control. Numerous 'before and after' type studies have shown that, in general, fewer motor vehicle crashes resulting in casualty crashes occur at roundabouts than at intersections containing traffic signals, stop, or give-way signs. Unfortunately, this same safety record does not apply to cyclists or pedestrians.

The primary reason for the improved safety record for motor vehicles is that the relative speeds of vehicles are considerably lower at a well-designed roundabout than for other types of at-grade intersections. Controlling speeds through roundabouts by their design is paramount in maximising the safety performance for all road users. The most important geometric considerations in controlling vehicle speeds through roundabouts are:

- Adequate sight distance should be provided to enable drivers to:
  – easily identify the intersection as a roundabout and comprehend their required path through the layout
  – observe the movements of other vehicles, cyclists and pedestrians travelling within and on the approaches to the roundabout
  – observe an acceptable gap in the circulating traffic and enter in a safe manner.
- The entry geometry should be designed to restrict drivers to a safe speed on entry to the roundabout.

Furthermore, motorcyclists are over-represented in crashes at roundabouts, therefore additional issues to be considered include:

- recognition of the roundabout – the design should provide for early recognition of the approaching form of the intersection
- visibility of the central island, particularly at night
- visibility of splitter islands
- frangible signs and posts that are more forgiving to motorcyclists
- skid resistant linemarking
- sight lines to motorcycles and sight lines of motorcyclists should not be blocked by landscaping, signage or island treatments
- the location of utility poles, particularly at exits from the roundabout
- using semi-mountable kerbs
- minimising the use of aprons and apron lips, and providing a larger central island.

Speed has been identified as a major contributing factor to the occurrence and severity of many crashes at intersections, including roundabouts. At rural intersections this factor is exacerbated due to the high-speed differential between conflicting movements. Austroads (2014) describes methods for reducing speeds on rural roads and includes a range of treatments for application at rural roundabouts.

Special consideration must be given to pedestrian movement(s) at roundabouts. While roundabouts are not necessarily less safe than other intersection types, children and elderly pedestrians feel less safe at roundabouts, particularly at exits. This is because, unlike traffic signals, roundabouts do not give priority to pedestrians over through or right-turning traffic, and some pedestrians may experience a reduction in accessibility. The consideration of pedestrians in relation to the provision and design of roundabouts is discussed in Section 5.2.

It is also important to note that several studies have shown that roundabouts increase the risk of cyclists being involved in a crash, compared to other types of intersection. Roundabouts designed with good entry curvature require entering drivers to slow down, provide more time for motorists to scan for cyclists, and consequently minimise cyclist crashes. Treatments for cyclists are presented in Section 5.3.

It should be noted that, although treatments can be provided for pedestrians and cyclists at roundabouts, they may not be the most appropriate intersection treatment at locations where there are high levels of cycle and pedestrian traffic and alternative treatments should be considered. Compared to signal-controlled intersections, roundabouts can present a significant impediment to pedestrian movement, particularly larger roundabouts with high volumes or speeds of motor vehicles. In such cases it may be very difficult for mobility-impaired pedestrians in particular to find an acceptable gap in traffic to cross the roundabout. Where pedestrian demand is likely to be significant the designer will need to consider means to accommodate pedestrians crossing. Treatments may include the provision of refuges in splitter islands (to facilitate multi-stage crossing), speed control through horizontal (e.g. entry angle) and vertical deflection (e.g. platform), designated pedestrian crossings (zebras), pedestrian-operated signals or grade-separated crossings. While the challenges of navigating larger arterial roundabouts as a pedestrian are most acute, conversion of sign-controlled local road intersections to roundabouts can also reduce pedestrian level of service by:

a. requiring pedestrians to move from their desire line to use the designated crossing setback from the roundabout
b. removing any priority pedestrians may have over motorists within the road rules.

Analysis of Victorian crash statistics by Austroads (2015b) suggested that just under half of crashes involving pedestrians at roundabouts resulted in a fatal or serious injury. Moreover, it was concluded that the majority of the severe crash problem at urban roundabouts involves cyclists and pedestrians. As such, effort is warranted in reducing the crash likelihood for these road users. Commentary 1 provides more information on the safety performance of roundabouts for general traffic, pedestrians and cyclists.

While pedestrians and cyclists have a higher crash risk than motor vehicles at roundabouts (particularly larger roundabouts in urban areas), the safety benefits to motorists has been demonstrated at a wide range of intersection sites in low and high-speed environments such as:

- local roads that have a collector or access function
- rural highways and roads
- freeway/motorway ramp terminals
- terminals of roads performing a motorway function
- arterial roads in urban areas.

However, these safety benefits to motorists should be considered within the wider context of potential safety disbenefits to cyclists and pedestrians, as well as the challenges these users have in navigating roundabouts. This is particularly true for local road and arterial road roundabouts in urban areas, where significant pedestrian and cyclist demand is likely. In such situations a satisfactory solution will be to design the roundabout with operating speeds consistent with Safe System principles where vulnerable users are present (i.e. 30 km/h at most, and ideally closer to 20 km/h). Speed measurements at about 40 single-lane and multilane roundabouts in Queensland found that less than 10% of roundabouts had 85th percentile speeds under 30 km/h at a distance of 20 m behind the hold line (McDonald 2018). This suggests current design practices are not achieving Safe System speeds.

The computer program ARNDT (A Roundabout Numerical Design Tool) can be used for analysis of the safety performance of roundabouts. The results of the analysis enable road designers to identify potentially hazardous geometry of proposed or existing roundabouts. The program is freeware and can be downloaded from the website (www.tmr.qld.gov.au). ARNDT uses the crash models developed for the five major crash types and the 'other' category (that occur at roundabouts) as shown in Figure A 2 of Appendix A. Appendix B provides a summary of the roundabout study that is the basis of the program. Designers are referred to Arndt and Troutbeck (1998) for detailed information.

Commentary 2 describes how roundabout geometric parameters may combine to effect crash rates.

Crash models for roundabouts in New Zealand have also been developed (Turner, Wood & Roozenburg 2006), and are also briefly described in Appendix A.

1.7 Traffic Capacity of Roundabouts

The performance of roundabouts is covered in the Austroads *Guide to Traffic Management Part 3: Transport Studies and Analysis* (AGTM Part 3) (Austroads 2020c) that includes techniques for capacity analysis of roundabouts, reference to software packages, and worked examples.

Traffic analysis is an important aspect of the design of roundabouts as it determines the number of lanes that are required on the entries, circulating roadway and exits to ensure an appropriate level of service for motorists.

Care should be taken in assessing the future traffic volumes and their patterns – refer to AGTM Part 3 and AGTM Part 4. It is possible that a site considered appropriate for a roundabout in the short to medium term may become inappropriate in the longer term, requiring extensive modification to the intersection. Designers should consider the potential to build flexibility into the design to accommodate possible future changes, particularly when changes to land use are likely to substantially alter traffic patterns. A whole-of-life approach should be used to assess the viability of a roundabout over its service life and to develop a strategy for the future, for example:

- upgrade a single-lane roundabout to a two-lane roundabout
- replace the roundabout with a signalised intersection or an interchange at a future date.

Wherever practicable, it is always preferable to design the 'ultimate' layout for a location so that appropriate land can be reserved for the future and the initial design provides a logical and efficient step toward the ultimate design.

1.8 Signalisation of Roundabouts

Signalisation of roundabouts is discussed in Section 4.6 of AGTM Part 6.

Typically, when an existing roundabout is performing poorly on one or two approaches during peak periods, the dominant approach (the approach that flows continuously and prevents traffic from another approach from entering) may be metered using traffic signals. This treatment is a cost-effective way of deferring replacement of the roundabout.

In circumstances where several roundabout approaches are performing poorly for extended periods, and a conventional signalised intersection is inappropriate, a roundabout may be fully signalised. A fully signalised roundabout has all junctions around its periphery signalised. A decision to fully signalise a roundabout will involve traffic modelling to ensure that these junctions can be coordinated to achieve the required capacity and performance in terms of delay. Geometric changes to an unsignalised layout may involve minor widening and realignment of entries to achieve improved saturation flows and improved capacity.

Other safety benefits of signalising a roundabout include:

- reduction in crashes resulting from poor judgement of gaps in circulating traffic
- reduction in the incidence of rear-end crashes between vehicles waiting to join the roundabout
- ability to provide pedestrian crossing facilities with active control
- increase in cyclist and motorcyclist safety as motorists would no longer need to spot and give way to two-wheeler riders.

Signalisation of roundabouts should be discouraged where approach speeds are high.

1.9 Roundabouts in High-speed Rural Areas

Austroads (2023d and 2010) discuss the crash benefit of installing roundabouts at rural cross-intersections (including those in areas with high speeds) at which there is a history of crashes involving crossing or right-turn (versus opposing) traffic. This treatment is cited as achieving an expected reduction of 70% in adjacent approach crashes but with an increase of 20% in lower severity rear-end crashes (Austroads 2009d). However, if the traffic flow on the lower volume road is less than about 200 vpd consideration could be given to using a staggered 'T' treatment (Austroads 2020d).

For more information designers should also refer to the Austroads *Guide to Road Design Part 4A: Unsignalised and Signalised Intersections* (AGRD Part 4A) (Austroads 2023c), *Road Safety Engineering Risk Assessment Part 9: Rural Intersection Crashes* (AP-T154-10) (Austroads 2010) and the Austroads *Guide to Road Safety Part 8: Treatment of Crash Locations* (AGRS Part 8) (Austroads 2015a).

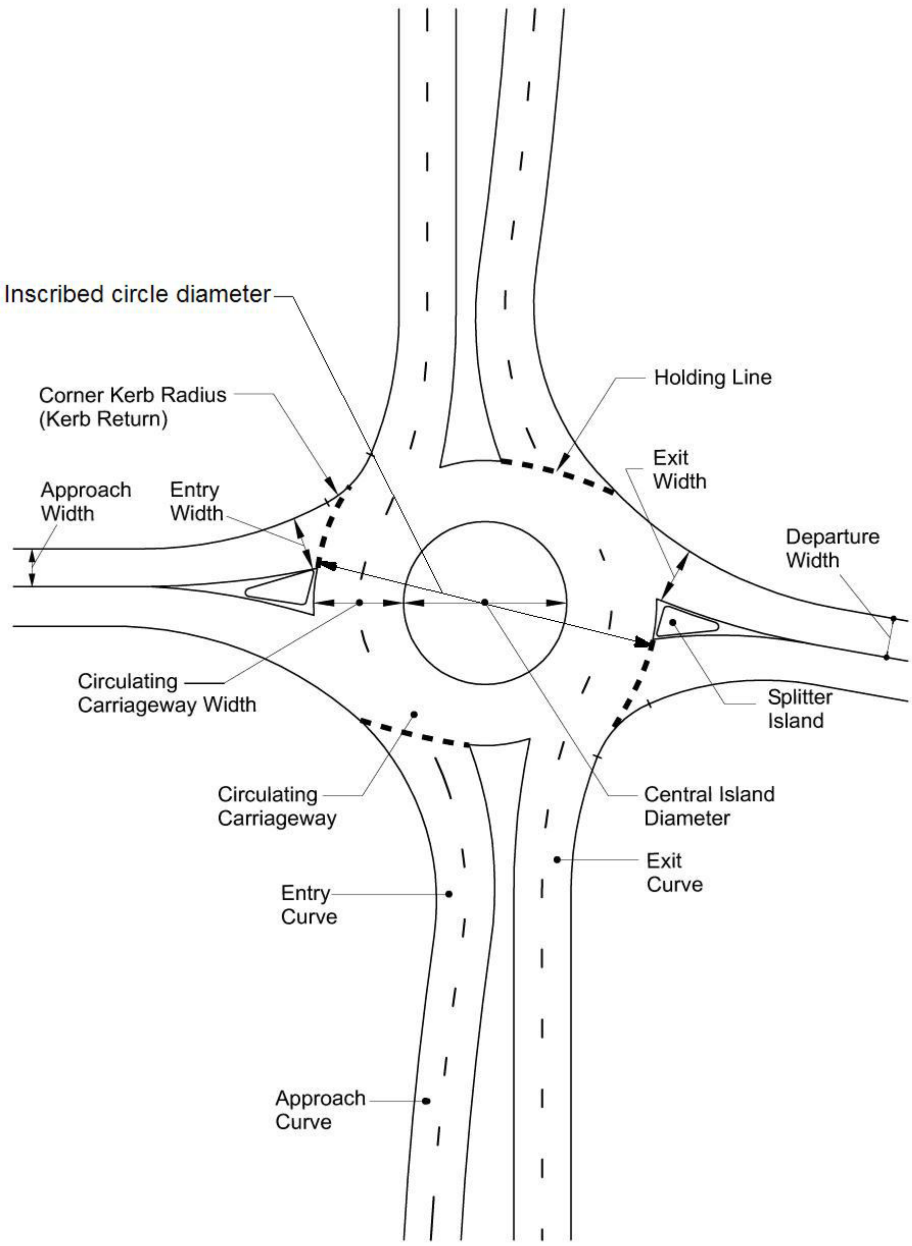
2. Design Principles and Procedure

This Guide uses the method of controlling speed of traffic entering roundabouts through the geometry of the roundabout entry, rather than within the roundabout where restriction through deflection requirements is essentially too late in the process of the driver negotiating the roundabout.

2.1 Terminology

Figure 2.1 illustrates the geometric elements of a roundabout and the terminology applied to them.

Figure 2.1: Geometric elements of a roundabout



Source: Department of Main Roads (2006).

2.2 Design Principles

The principles that should be applied to achieve a safe and efficient roundabout design are:

- The roundabout should be clearly visible from the approach sight distance at the road operating speed in advance of the roundabout approach.
- The number of legs should preferably be limited to four (although up to six may be used at an appropriately designed single-lane roundabout).
- Legs should preferably intersect at approximately 90°, especially for multilane roundabouts.
- It is essential that appropriate entry curvature is used to limit the entry speed.
- Entry speeds should be established after considering the types of users, e.g. cyclists and pedestrians that are expected to travel through the roundabout. Where there are likely to be significant cyclist or pedestrian demand, entry speeds should be designed around a Safe System speed of under 30 km/h (Austroads 2015b).
- Exits should be designed to enable vehicles to depart efficiently.
- The periphery of the roundabout (inscribed circle diameter) must be large enough to accommodate all entries and exits to an appropriate standard without them overlapping.
- The circulating roadway should be wide enough to accommodate the swept paths of the design vehicle/s plus clearance to kerbs for both through movements and right-turn movements.
- Entering drivers must be able to see both circulating traffic and potentially conflicting traffic from other approaches early enough to safely enter the roundabout.
- Splitter islands with pedestrian refuges and/or pedestrian platforms should be provided, and road widths should be kept to a minimum to minimise crossing distances.
- Sufficient entry, circulating and exit lanes should be provided to ensure that the roundabout operates at an appropriate level of service.
- The target speed for lane sharing should be < 30 km/h (Note: the design methods available to obtain this speed need to be developed); otherwise, consideration should be given to providing a separate facility for cyclists.

The principles of roundabout design as they apply to urban arterial and rural intersections are similar and should always be achieved when designing new roundabouts.

The use of roundabouts in conjunction with motorways/freeways, either as a ramp terminal treatment or as a grade-separated roundabout, is provided in Section 6 of the Austroads *Guide to Traffic Management Part 6: Intersections, Interchanges and Crossings Management* (AGTM Part 6) (Austroads 2020d), and the relative advantages and disadvantages are presented. However, the design principles for this application are the same as for the use of a roundabout at an isolated site.

In local streets the operational objectives are not the same as those on arterial roads and, because of constraints such as cost and limited space and the low-speed environment, the design standards will be quite different to those that are applicable on arterial roads.

2.3 Design Procedure

Section 4 of the Austroads *Guide to Road Design Part 4: Intersections and Crossings: General* (AGRD Part 4) (Austroads 2023b) provides a general design process that applies to all intersections including roundabouts. This process covers considerations that are essential for intersection design such as traffic data, types of users, particularly cyclists and pedestrians, future development that may influence a design and constraints on design, e.g. topography, budget, etc.

The geometric design of a roundabout should be preceded by a traffic analysis to determine the number of circulating and entry lanes that will be required initially and into the future (refer to the *Austroads Guide to Traffic Management Part 3: Transport Studies and Analysis Methods* (AGTM Part 3) (Austroads 2020c)). The number of lanes is a basic input to the design process.

The following provides the design procedure (Figure 2.2) specifically for the layout design of roundabouts. The need to undertake some of the steps will depend on the nature of the site. For example, the design of a roundabout involving two local residential streets may be a relatively simple exercise where traffic analysis is unnecessary where the existing corner radii are used as controls for the location of the circulating roadway. On the other hand, an intersection between two arterial roads will usually require detailed traffic analysis and may require several iterations to establish the optimum design.

Figure 2.2 should be used in conjunction with Table 2.1 that provides considerations and cross-references relating to the design steps in Figure 2.2.

Figure 2.2: Design procedure for roundabouts

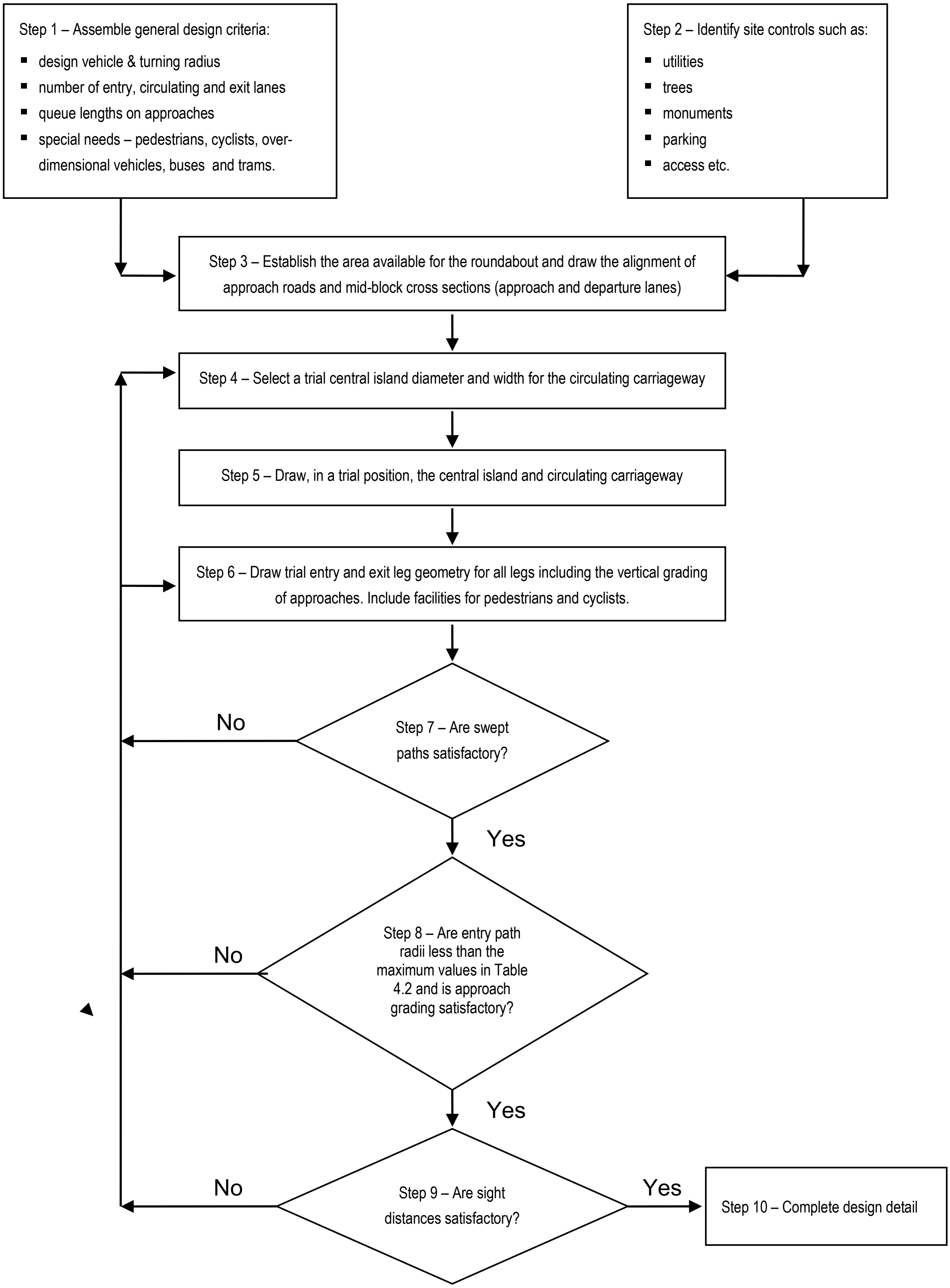


Table 2.1: Design procedure – considerations and cross-references

Step	Consideration	Cross-reference
Step 1 Assemble general design criteria.	Design vehicle and turning radius.	AP-G34-23
	Number of entry, circulating and exit lanes. Queue lengths on approaches.	AGTM Part 3
	Special needs – pedestrians, cyclists, buses and trams.	Section 5 (of this Guide) AGTM Part 6 AGRD Part 4, sections 6, 8 and 9
Step 2 Identify site controls.	Road users.	AGTM Part 6
	Topography and land availability Environment and heritage Physical constraints Utilities Parking, etc.	AGRD Part 4, Section 3 AGRD Part 6B
Step 3 Establish area available, alignments and cross-sections.	May be affected by a range of factors including topography, watercourses and buildings.	AGRD Part 1 AGRD Part 3
Step 4 Select central island radius and circulating carriageway width.	Central island.	Section 4.4 and Table 4.1
	Circulating carriageway.	Section 4.6, Table 4.3 and Table 4.4
Step 5 Draw central island and circulating carriageway in trial position.	Check that inscribed circle can accommodate all legs.	AGRD Part 3
	If inscribed circle is too close to road reservation boundary, a new location should be trialled.	AGRD Part 6B
	Clearance from kerbs to boundary must accommodate drainage, existing and proposed utilities, pedestrian and bicycle paths, etc.	AGRD Part 6A
Step 6 Draw trial entry and exit leg geometry for all legs including vertical including vertical alignments.	Mid-block cross-section should be drawn and extended to the roundabout to provide a reference for entry path.	AGRD Part 3
	Ensure that the vertical gradients on the roundabout approaches are within desirable limits. Consider use of speed reducing treatments where approach speed is ≥ 80 km/h.	Section 4.10.2
	Where bicycle lane is provided on approach, consider appropriate treatment.	Section 5.3
	Provide a fast exit (straight or large curve) where there is no pedestrian or parking activity on the departure. If there is activity, provide a tighter exit curve to reduce exit speed.	Section 5
	Kerbs around corners between entries and exits should be coincident with the inscribed circle. If the kerb is outside of the inscribed circle, an area of additional pavement will result adjacent to the circulating lane. This additional width can enable left-turning vehicles to 'slip' around the corner and lead to safety and operational issues.	Figure 2.1

Step	Consideration	Cross-reference
Step 7 Check that the maximum entry path radii have been achieved.	Draw entry path radii in accordance with Section 4.5.3. If an entry path radius is greater than that shown in Table 4.2, an alternative geometric layout should be trialled. Alternatively, use the ARNDT roundabout program. The maximum entry path criteria are deemed to be met if the limits of the roundabout safety parameters in ARNDT are not exceeded.	Section 4.5.3 and Table 4.2
Step 8 Check swept paths of the design vehicle for all traffic movements including the circulating carriageway.	Provide 0.5 m clearance between the swept path of the design vehicle and the line (i.e. face) of kerb and 1.0 m clearance between swept paths. If necessary, clearances are not achieved, the geometric layout should be modified.	AP-G34-23
Step 9 Check that sight distances are satisfactory.	Check approach sight distance and sight distance for drivers from a position at the holding line of the roundabout. If any sight distance criteria are not met, modify the geometry layout as necessary.	Section 3 of the AGRD Part 4A
	Check sight distance for driver from a position at the holding line of the roundabout.	Figure 3.1 and Table 3.1
Step 10 Complete design detail.	Complete design by drawing lighting, signs and markings, and landscaping, and considering other roadside design and safety issues.	Section 6 and 7 AGRD Part 6 AGRD Part 6A AGRD Part 6B

3. Sight Distance

3.1 Introduction

Roundabouts must be designed to provide the same approach sight distance (ASD) as other intersections – refer to the Austroads *Guide to Road Design Part 4A: Unsignalised and Signalised Intersections* (AGRD Part 4A) (Austroads 2023c). However, drivers at the holding lines at roundabouts are provided with minimum gap sight distance (MGSD) rather than the safe intersection sight distance (SISD).

3.2 Sight Distance Criteria

Three sight distance criteria must be applied to the combination of vertical and horizontal geometry at roundabouts as illustrated in Figure 3.1. These criteria affect the positioning of signs, landscaping, poles, and other roadside furniture.

It is important to note that:

- Criteria 1 and 2 are both mandatory requirements.
- Criterion 3 is not mandatory.

Within the sight triangles/zones subject to Criteria 2 and 3, it is acceptable to allow momentary sight line obstructions by objects such as poles, sign posts and narrow tree trunks.

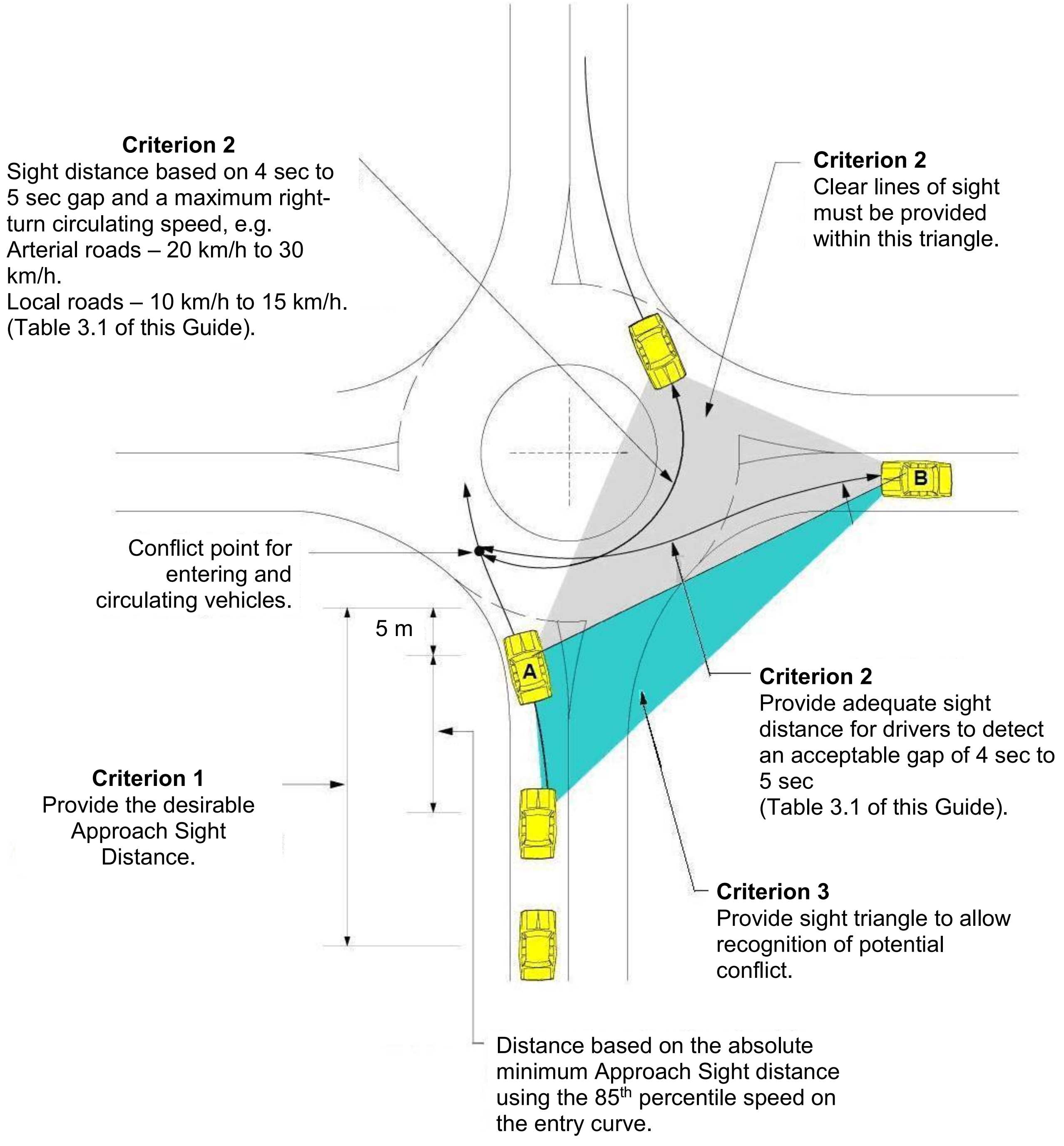
3.2.1 Criterion 1

The alignment on the approach should be such that the driver has a good view of the splitter island, the central island and, preferably, the circulating carriageway. Adequate ASD should be provided to the holding line/s. Where this cannot be achieved, ASD to the (approach) nose of the splitter island should be provided as an absolute minimum.

ASD is defined and discussed in Section 3 of AGRD Part 4A. The required ASD is based on the speed of vehicles on the geometric element prior to the entry curve. This may apply to a curve where reverse curves are used on the approach, or a straight alignment if a single-entry curve is used. The ASD is measured from a car driver’s eye height (1.1 m) to pavement level (0.0 m).

Designers should refer to Table 3.1 and Table 3.2 of AGRD Part 4A that respectively provide approach sight distance values and corrections that should be applied to the values to allow for gradient on the approach.

Figure 3.1: Sight distance criteria for roundabouts



Note: Values for approach sight distance are provided in Table 3.1 of AGRD Part 4A.

Source: Adapted from Department of Main Roads (2006).

3.2.2 Criterion 2

This criterion relates to a car driver entering a roundabout having adequate sight distance to two potentially conflicting movements within the roundabout, namely:

- a vehicle entering from the approach immediately to the right
- a vehicle travelling on the circulating roadway.

Approach immediately to the right

Referring to Figure 3.1, a driver in car A, stationary at the roundabout holding line, should have a clear line of sight to an entering vehicle (car B) on the approach immediately to the right, for at least a distance representing the travel time equal to the critical acceptance gap for the driver of car A. It is measured from a driver's eye height of 1.1 m (i.e. in car A) to an object height of 0.65 m (indicators on car B).

For a driver waiting at the holding line, the distance should be based on the 85th percentile speed of 'free' vehicles entering the roundabout from the approach immediately to the right of the driver. For an appropriately designed roundabout the speed may be 50 km/h for an arterial road and 25–30 km/h for a local residential street. Alternatively, the ARNDT program may be used to determine likely 85th percentile speeds for any horizontal geometric element of the roundabout.

Note that speeds determined by the point mass formulae (using the maximum degree of side friction values) may be much lower than speeds actually used by drivers at roundabouts. One study has shown that the side friction used by the 85th percentile driver can be as high as 0.48 on smaller to moderate radii curves at roundabouts in higher speed areas.

The distance is measured from the conflict point along each vehicle's travel path as shown in Figure 3.1. The vehicle path can be determined using the ARNDT program. If vehicle paths are not calculated, it is acceptable to measure this distance from 5 m behind the holding line directly to the previous approach.

A critical gap of five seconds, giving a distance of 70 m (based on an entry speed of 50 km/h for car B) is considered the minimum for arterial road roundabouts. At sites in local streets the minimum Criterion 2 sight distance should be based on a critical gap of four seconds.

Circulating roadway

The Criterion 2 sight distance should also be checked in respect to vehicles on the circulating carriageway having entered from other approaches (i.e. approaches other than the approach immediately to the right). The speed of these vehicles should be based on the 85th percentile speed on the circulating carriageway and may be calculated using the ARNDT program.

These speeds may range from 15 km/h for small urban roundabouts to 60 km/h for large rural roundabouts. Criterion 2 sight distances for vehicles using roundabouts are shown in Table 3.1.

Table 3.1: Criterion 2 sight distances

85th percentile speed (km/h) on the approach immediately to the right, or on the circulating roadway	Criterion 2 sight distance (m)	
	Local residential street roundabout critical acceptance gap 4 sec	Arterial road roundabout critical acceptance gap 5 sec
20	22	28
30	33	42
40	44	56
50	55	70
60	67	84

3.2.3 Criterion 3

It is also desirable that a driver (car A) approaching a roundabout is able to see other entering vehicles (car B) well before that driver reaches the holding line. The Criterion 3 sight triangle shown in Figure 3.1 allows an approaching driver (car driver eye height of 1.1 m) time to stop and avoid a vehicle driving through the roundabout (an object height of 1.1 m representing car B driver eye height).

It can be seen from Figure 3.1 that the absolute minimum sight distance is used to determine the side of the triangle on the approach to the intersection relating to car A. This is in response to concerns in some jurisdictions that a larger sight triangle may lead to higher entry speeds.

3.2.4 Pedestrian Visibility

Pedestrians crossing the roundabout should be visible to motorists approaching and departing from the roundabout. Moreover, pedestrians should have sufficient sight distance to be able to detect and respond to an acceptable gap in order to cross. This will apply both from the kerb and any central splitter island. Street furniture (especially fencing and vegetation) should be either sufficiently low or transparent that pedestrians, including children, can readily see beyond the obstacle (and equally, that they are not masked to motorists).

Footpaths, kerb ramps and pedestrian refuges in splitter islands should be located so as to minimise the deflection from the pedestrian desire line but also ensure adequate visibility.

3.2.5 Other Visibility Considerations

At any roundabout, designers must provide the sight distance quantified and described above. A driver must also be provided with sufficient visibility to readily assess the driving task. The sight distance required for this is not quantified precisely and only general guidance can be given.

The following observations are as relevant for roundabouts as for other types of intersections:

- It is better to position a roundabout/intersection in a sag curve rather than on a crest.
- It is important to avoid placing a roundabout/intersection just over a crest where the layout is obscured from the view of approaching drivers.
- At-grade separated roundabouts, particularly where there may be a structure (e.g. pier) in the central island or a bridge railing, the structure or railing should be located and designed to ensure that the sight distance requirements are met. Any safety barriers used to protect rigid objects such as piers, structures and embankments may also interfere with visibility and must be located to avoid this interference.
- Signalised roundabouts may have multilane approaches both on the entries and the circulating carriageway. It is essential that signal displays are visible to all road users to whom they apply. Approaching vehicles should be able to sight the traffic signal from a minimum distance equivalent to Criterion 1. Sight distance Criteria 2 and 3 are desirable in the event the signal fails and the intersection reverts to operation as an unsignalised roundabout.

3.3 Stopping Sight Distance for Trucks

The sight distance requirements for roundabouts discussed above for intersections, are based on cars. However, to ensure that trucks approaching the roundabout are able to stop safely, the stopping sight distance for trucks (SSDT) should also be provided:

- on tight horizontal curves (the lateral sight distance restrictions are often critical, particularly at intersections in hilly terrain or near bridge piers)
- on or near crest vertical curves
- at intersections used by a significant volume of large or special vehicles.

Where a structure passes over the approach to a roundabout and the approach is in a sag curve, the design should be checked to ensure that SSDT is provided through the underpass. The critical vehicle in this case is a high truck in which the driver’s eye height is 2.4 m, and the object is a car tail-light 0.8 m in height. Refer also to the Austroads *Guide to Road Design Part 3: Geometric Design* (AGRD Part 3) (Austroads 2016b) in which values for SSDT and corrections for grade are given.

4. Geometric Design

4.1 Introduction

Roundabouts can be used at suitable sites on arterial roads, collector roads and local streets. In addition, they may be used with the major traffic movement grade separated above or below the roundabout, or in pairs at closely spaced intersections or freeway/motorway interchanges. The appropriate use of roundabouts and road user considerations are covered in the Austroads *Guide to Traffic Management Part 6: Intersections, Interchanges and Crossings Management* (AGTM Part 6) (Austroads 2020d). This section provides guidance on the method and parameters to be used in the geometric design of roundabouts.

In designing a roundabout, appropriate entry speeds need to be adopted, and these speeds depend on the function and types of approach roads and the expected road users. As a guide, for an appropriately designed roundabout, the speed may be 50 km/h for an arterial road and 25–30 km/h for a local residential street.

4.2 Number of Legs

Single-lane roundabouts can operate satisfactorily with more than four legs. However, the provision of more than four legs or legs at angles other than approximately 90° should be avoided for multilane roundabouts as this can create conflict at exits. Drivers can also experience difficulty in identifying the appropriate lane choice required for left, through and right turns on some approaches – Section 4.5.2 and Commentary 20, AGTM Part 6.

4.3 Number of Entry, Circulating and Exit Lanes

4.3.1 Introduction

In general, the number of roundabout lanes (entry, circulating, and exit lanes) provided should be limited to the minimum number that achieves the desired capacity and operating requirements for the projected future traffic volumes. This is because the rates of several types of crashes at roundabouts increase with an increase in the number of lanes provided. For this reason, it is desirable to limit the number of circulating lanes to a maximum of two, although roundabouts with three circulating lanes have operated with an acceptable level of safety and efficiency at a number of locations (relative to the alternative of providing traffic signals).

Two-lane roundabouts on single carriageway roads can promote overtaking within the roundabout, especially if there are no overtaking opportunities in close proximity on the approach to the roundabout. This situation causes driver frustration and is often the topic of complaints by motorists (including heavy vehicle operators). This situation should be avoided where possible by:

- providing a single-lane roundabout until traffic volumes warrant the use of a two-lane facility, or
- providing single-lane only for the through movement, or
- providing overtaking lanes prior to the approach.

A single-lane roundabout may be provided initially and upgraded in the future (say in 10 to 15 years) to a two-lane facility as traffic volumes dictate. In cases where this is applicable, it may be desirable to design the periphery of the roundabout and outside kerbs of the entries and exits (including drainage) to suit the ultimate location and allow for the central island to be reduced in size to accommodate the second lane.

4.3.2 Number of Entry Lanes

The number of entry lanes controls the capacity or level of service on an approach. The number of lanes is determined from capacity analysis – Austroads *Guide to Traffic Management Part 3: Transport Studies and Analysis Methods* (AGTM Part 3) (Austroads 2020c) – which will also determine the appropriate lane discipline (i.e. left, through, right) on the approaches.

Irrespective of capacity considerations it is generally important on arterial roads that lane continuity is available through roundabouts; that is, a roundabout serving a two-lane approach on a duplicated arterial road should have two entry lanes even if the calculations show that one lane would have adequate capacity.

4.3.3 Number of Circulating Lanes

The number of circulating lanes from any particular approach must be equal to or greater than the number of entry lanes on that approach. It is not essential to provide the same number of circulating lanes for the entire length of the circulating carriageway as long as the appropriate multilane exits are provided prior to reducing the number of circulating lanes. An example of this treatment is shown in Commentary 3.

4.3.4 Number of Exit Lanes

The number of exit lanes must not be greater than the number of circulating lanes. On multilane roundabouts the number of exit lanes is based on the lane usage as determined by the pavement arrows on the approaches. Where no pavement arrows are shown, the number of exit lanes should equal the number of circulating lanes prior to the exit.

At some multilane roundabouts, a two-lane exit is reduced to one lane beyond the exit to match mid-block conditions and it is necessary to provide a merge area on the departure. It is desirable that the two lanes extend from the exit a distance equivalent to six seconds of travel time (absolute minimum of four seconds), followed by a merge length based on 0.6 m/s lateral shift. It is also desirable that a run-out (e.g. a shoulder) area be provided as an escape path in the event of potential conflict between merging vehicles.

4.3.5 Left-turn Slip Lanes

Provision of a left-turn slip lane is beneficial on approaches where a significant proportion of the traffic turns left. In some cases, the use of a left-turn slip lane can avoid the need to build an additional entry lane.

The two design options for the provision of left-turn slip lanes at roundabouts are the same as those used for other types of intersection, namely:

- a high entry angle left-turn lane
- a free-flow left-turn lane involving an acceleration lane in the road being entered.

Traffic management characteristics of these options and illustrations are provided in the AGTM Part 6 and geometric design details are provided in the Austroads *Guide to Road Design Part 4A: Unsignalised and Signalised Intersections* (AGRD Part 4A) (Austroads 2023c).

4.3.6 Special Use Lanes

The provision of bus lanes and transit lanes on approaches to and through roundabouts is not common but may be appropriate depending on the need for the facility, the traffic movements required and site conditions.

Where necessary and only in low-speed environments, trams may be accommodated within roundabouts. The trams on approaches pass through the splitter islands, across the circulating carriageway and through the central island. Illuminated flashing signs are provided to warn motorists of the presence of trams and a contrasting surface may be used to delineate the tram crossings. However, it is important that:

- the residual areas remaining in splitter islands and the central island are sufficiently large for the treatment to be recognised as a roundabout and to accommodate pedestrians in the splitter islands
- the design ensures that the negotiation speed for general traffic movements through the roundabout is slow to enable drivers to have additional time to scan for trams and to stop and give way.

4.4 Central Island

4.4.1 Central Island Shape

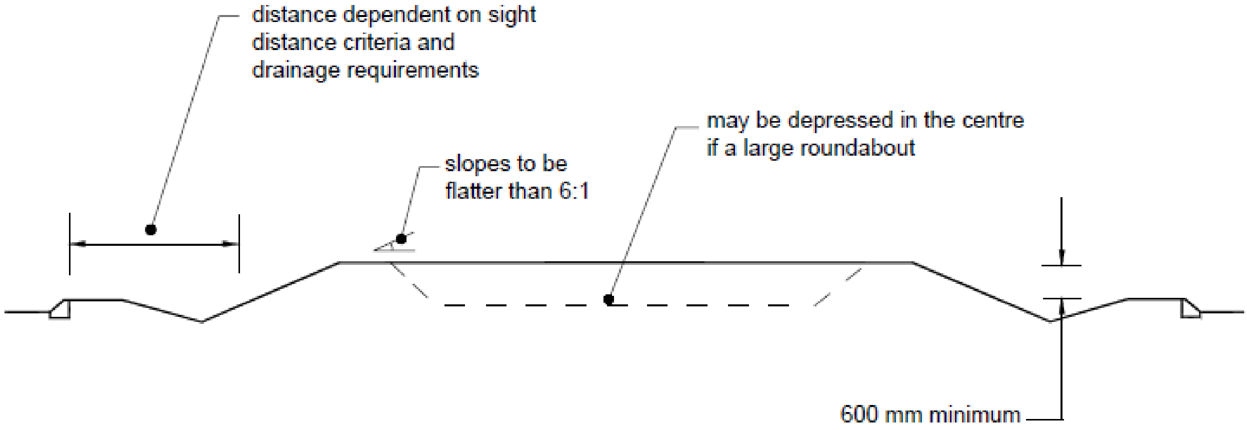
Central islands should preferably be circular as changes in curvature of the circulating carriageway result in differential speeds and increase driver workload. However, elliptical, oblong or other shapes may be necessary to suit unusual and/or constrained site conditions.

In situations where the central island is not circular, there will be different circulating speeds for different sections of the circulating carriageway. For example, when passing through an elliptical roundabout (Figure 4.16) right-turning drivers on two of the entries will find that the radius of their turning path decreases and becomes more difficult due to the compound curves. For this reason, elliptical roundabouts should only be used where the operating speed on the approach road is ≤ 80 km/h. A circular roundabout at this type of location, although quite large, would provide a safer treatment and is therefore desirable, if space permits.

Wherever possible, roundabout central islands should be raised to improve visibility of the island for approaching drivers and to assist drivers to recognise that they are approaching a roundabout. This can be achieved by using kerbing, preferably a semi-mountable kerb, which is more forgiving to errant motorcyclists. Where raised central islands are provided on flat terrain, the top of vegetation within the roundabout should not impede sight distance for a driver entering the roundabout to a vehicle moving around the central island measured to a car indicator height of 0.65 m (Figure 3.1). However, on very large roundabouts, landscaping can be higher outside of areas over which a driver’s sight lines pass.

On large central islands (nominally greater than 20–25 m in diameter) on arterial roads, the island may be raised on the periphery and depressed in the centre as shown in Figure 4.1. In such cases, it is important that a berm be provided behind the kerb to improve the definition and visibility of the central island and to ensure that the open drain does not create a hazard. Refer to the Austroads *Guide to Road Design Part 3: Geometric Design* (AGRD Part 3) (Austroads 2016b) for guidance on forgiving open drain profiles. On very large roundabouts planting, including large trees can be provided in the depressed area.

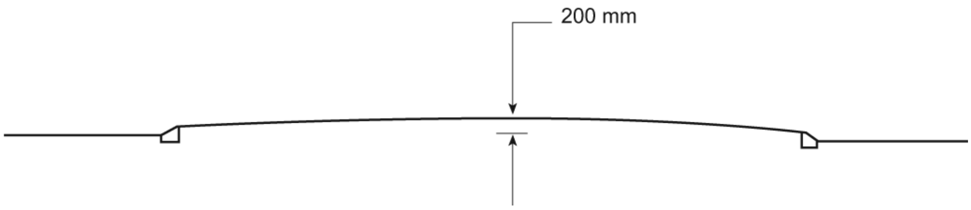
Figure 4.1: Schematic treatment of a central island on large roundabouts



Source: Department of Main Roads (2006).

On smaller roundabouts that have a central island diameter less than 20–25 m, a raised central island may not be possible due to sight distance requirements across the island. In this case, mounding the roundabout to a height of 0.2 m to facilitate drainage (Figure 4.2) and paving of the surface are appropriate treatments. Alternatively, low ground cover can be provided as long as sight lines across the central island are not impeded by the vegetation.

Figure 4.2: Schematic treatment of a central island on smaller roundabouts



Source: Department of Main Roads (2006)[3]*.*

4.4.2 Factors Affecting Central Island Size

The size of the central island of a roundabout may be influenced by the:

- cross-sections of the intersecting roads
- entry design required to slow vehicles to the desired entry speed
- design vehicles that must be accommodated in the circulating roadway
- need to accommodate satisfactory geometry for entries and exits
- desired level of service, particularly for heavy vehicles.

The central island needs to be large enough to achieve the desired geometry, but not so large that excessively high entry or circulating speeds are encouraged. On major arterial roads the central island radius should be limited to a maximum of 75 m (desirably 50 m). Larger radii will encourage high circulating speeds and may encourage wrong-way movements if drivers do not perceive the circulating carriageway as a roundabout. These larger radii should not be required for the usual design vehicles (e.g. prime mover with semi-trailer; B-double), but may be necessary where a road train is the design vehicle or for roundabouts that are grade-separated.

4.4.3 Central Island Radius

Larger roundabouts enable better entry geometry to be designed, which leads to a reduction in entering vehicle speeds. A larger roundabout will also reduce the angle formed between the entering and circulating vehicle paths, thus reducing the relative speed and crash rates between these vehicles.

In general, roundabouts in high-speed areas need to be larger to enable better entry and approach. Geometry should be designed to reduce the high approach speeds. The design of these roundabouts is more critical than that for roundabouts located in low-speed areas.

Table 4.1 provides a guide for the selection of the central island radius for a circular roundabout. The desirable central island radius provides an optimum safety outcome, while central islands larger than the desirable radius can result in increased circulating speeds and increased conflict between circulating and exiting traffic (refer Section 4.9). However, they also provide greater opportunity to provide the preferred geometric alignments or conditions, such as the entry curve geometry, which are outlined later in this section.

The criteria in the Table 4.1 should enable acceptable entry geometry to be achieved, refer to Table 4.2. The desirable values given in Table 4.1 should be used as a starting point whenever possible, as they generally produce lower overall crash rates than those produced by the minimum values (refer to notes 2 and 3 in Table 4.1).

Table 4.1: Guide for selecting the minimum central island radius for a circular roundabout

Desired driver speed on the fastest leg prior to the roundabout (km/h)	Central island radius of a single-lane roundabout (m)		Central island radius of a two-lane roundabout (m)		Speed reduction treatments required prior to the entry curve(1)
	Minimum(5)	Desirable	Minimum(5)	Desirable	
≤ 40(2)	5(4)	10	8	12	No
50(2)	8	11	8	12	No
60(3)	10	12	14	16	No
70(3)	12	18	18	20	No
80(3)	14	22	20	24	Desirable
≥ 90(3)	14	22	20	24	Yes

1 *Refer to Section 4.5.2 for the various types of speed reduction treatments.*
2 *The desirable central island radii listed for these speeds generally provide sufficient size splitter islands for storage of pedestrians combined with desirable entry curvature. The minimum central island radii generally do not. In addition, the desirable values will generally produce a lower overall crash rate than what the minimum values will.*
3 *The desirable central island radii listed for these speeds provide a maximum decrease in speed between the entry curve and a right turn on the circulating carriageway of 20 km/h. This minimises the number of potential single vehicle crashes on the circulating carriageway. The minimum central island radii are associated with values up to 30 km/h. In addition, the desirable values will generally produce lower overall crash rates than what the absolute values will.*
4 *Minimum central island radius where the design right-turn vehicle is a single unit truck is 7 m.*
5 *The minimum central island radii should typically only be selected for an initial central island radius in constrained brownfield sites. Selection of these radii may lead to some geometric design elements not complying with normal design domain criteria.*

Source: Queensland Department of Transport and Main Roads (2021b) and Queensland Department of Transport and Main Roads (2021a).

The criteria in Table 4.1 are based on the following:

- the roundabout has four legs
- each leg is at approximately 90° to adjacent legs
- the centreline of each leg goes through the centre of the roundabout
- for two-lane roundabouts, each leg comprises two lanes
- kerbing exists on both sides of all legs
- there are no medians on any of the approaches
- each leg has the same desired speed prior to the roundabout
- the largest right-turning design vehicle is a semi-trailer
- the design vehicle swept path remains on the pavement (does not require an encroachment area).

If any of the above conditions do not apply (which is usual), the values given in Table 4.1 will need to be changed to suit the specific requirements of the site and to obtain the maximum entry path radii in Table 4.2. Generally, the central island radius will need to be increased to allow for the following conditions:

- the roundabout has more than four legs
- the angle between any adjacent roundabout legs is considerably more or less than 90°
- the centreline of some or all of the legs in the direction of the central island passes considerably to the left of the centre of the roundabout
- there are shoulders and no kerbing on some or all of the legs
- there are medians on some or all of the approaches
- the design vehicle is larger than a semi-trailer.

In constrained areas the minimum values given in Table 4.1 can generally be reduced to allow for any of the following conditions (provided the maximum entry path radii in Table 4.2 are still obtained):

- the roundabout has three legs
- for two-lane roundabouts, some of the legs comprise one lane
- the desired speeds on some of the approaches are significantly lower than on others
- encroachment areas are used for the design vehicle, e.g. garbage truck at local street roundabouts
- other considerations apply, e.g. the roundabout will form an overpass or underpass with a highway or motorway.

4.5 Approach and Entry Geometry

4.5.1 General

The approach and entry treatment, involving either single or multiple curves, is the most important geometric parameter to be designed at roundabouts as it controls the speed of entering traffic and consequently the safety performance of the roundabout. Aligned with the Safe System principles, a well-designed roundabout achieves lower relative speeds of vehicles primarily owing to the application of appropriate entry curvature, which limits the:

- speed on the entry, which minimises rear-end type crashes at this location
- speed at which drivers can enter the circulating carriageway and the angle formed between entering and circulating vehicle paths. This minimises the relative speed between entering and circulating vehicles and the crash rate between these vehicle streams
- potential for fatal and serious injury by establishing angles at conflict points to minimise the impact of a crash
- decrease in speed required on the circulating carriageway. This minimises single vehicle crashes on the circulating carriageway
- potential risk of a fatal or serious injury to pedestrians and cyclists.

The approach treatment (except for small roundabouts on local roads) should include a raised median (or splitter) island on the approach and a kerb along the left side of the approach which, in conjunction with the approach alignment, creates a physical restriction that slows drivers. The limits of the kerb and median islands adopted on the approach, should be determined considering the appropriate sight distance to the commencement of kerb and median island. This is particularly important where the roundabout is partially (or fully) obscured due to vertical geometry on the approach.

Section 4 of AGTM Part 6 presents three ways of achieving good roundabout approach geometry:

- a single-entry curve to the left, applied generally
- reverse curves, for potentially minimising single vehicle crashes on road approaches with operating speeds ≥ 80 km/h
- blisters, suitable for urban low-speed environments where a single-entry curve option is not practicable.

Whilst the speed of a motorcycle is not as effectively reduced by an entry curvature when compared to a passenger vehicle, the performance of motorcyclists at roundabouts is catered for by current design principles. Alternative treatment to assist in the reduction of entry speed may also be considered, particularly on approaches with high speeds (Section 4.5.2).

Specific guidance on geometric methods to achieve entry and circulating speeds of less than 30 km/h are still being developed and trialled. These are being assessed and will be included in future updates of this guide. The use of vertical displacement devices is an option to maintain reduced approach speeds, particularly in urban contexts. Attention is drawn to the Austroads *Guide to Traffic Management Part 8: Local Street Management* (AGTM Part 8) (Austroads 2020b).

Appendix C provides guidance on methods to improve roundabout entry geometry.

4.5.2 Approach and Entry Treatments

The design of approaches to roundabouts on rural roads is possibly more critical than for roundabout approaches in urban areas, as drivers can be travelling on rural roads for long distances, and for long periods of time, and so may be less alert. It is therefore especially important to consider the use of speed reducing devices for approaches on rural roads. For any approach geometry, careful consideration should be given to the application of superelevation on the approaches. The superelevation of the entry curve will be nominally 2–3% along the left-hand approach curve.

The Safe System threshold for a pedestrian or cyclist crash is 30 km/h (i.e. there is a 10% chance of a fatality when vehicles impact a pedestrian or cyclist at 30 km/h). Therefore, the design should aim for roundabout entry speeds of 30 km/h or below unless separated bicycle facilities are provided, or where there are high numbers of pedestrians on adjacent footpaths or crossing the road at the roundabout.

Single-entry curve approach

The minimum treatment is the provision of a left-turning entry curve on the immediate approach to a roundabout (Figure 4.3). An appropriate entry path radius (Section 4.5.3 and Table 4.2) on the entry curve is essential to encourage drivers to slow down before reaching the circulating carriageway. In higher speed areas (≥ 80 km/h) the curve should be long enough to cut entirely across the prolongation of the approach road. The entry curve radius should not be so large as to result in an unacceptably high-speed entry onto the circulating carriageway and therefore should be determined by the process in Section 4.5.3.

Figure 4.3 shows the kerb line of the splitter island placed to be tangential with the central island. While this method has proven satisfactory, some road agencies prefer the prolongation of the splitter island kerb to pass through a point in the circulating roadway about 1.5 m from the central island. This is done to assist heavy vehicle drivers to ensure that the vehicle tracks on the pavement rather than mounting the island, and also assists drivers to change their steering from one direction to the other. Other state road agencies cater for this by providing a short horizontal straight between the entry curve and the circulating carriageway. In this case, a length of 5 m is usually sufficient. Alternatively, providing spirals at the ends of each reverse curve may also achieve a satisfactory result.

Approach treatments for high-speed areas

The use of a single-entry curve has the potential to require an excessive decrease in speed at the start of the entry curve, particularly in areas of high approach speeds. This may lead to an increased rate of single vehicle crashes on the entry curve. It is important that treatments are applied in these situations to alert drivers to a change in environment and encourage a more gradual reduction in vehicle speeds. These treatments are usually required only in areas with high desired speeds (≥ 80 km/h) and may comprise of one or more of the following:

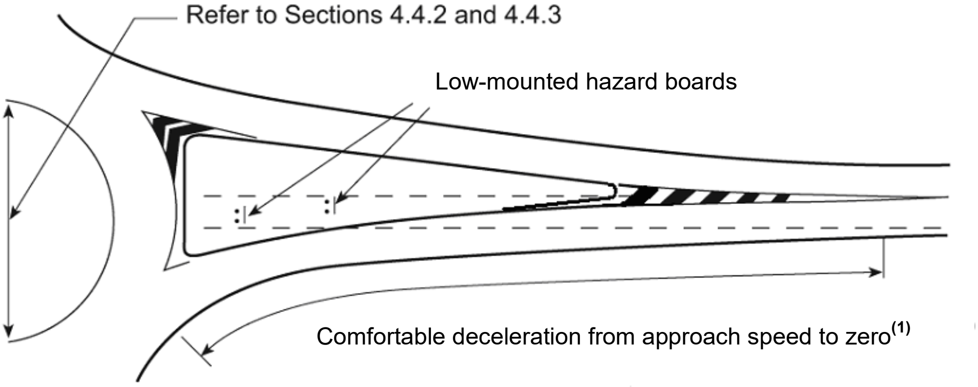
- successive reverse curves
- a long median island and a kerb on the left side of the approach to provide the perception of a narrowing of the road and ‘funnelling’ of traffic
- rumble strips
- creating a lower desired speed on the approach by the use of local treatments giving the impression of a restriction to the driver, such as:
  - dense planting close to the edges of the approach carriageway (sight lines must not be impeded)
  - narrower total cross-section (only on horizontal straights)
  - guide posts at decreasing spacing towards the roundabout
- large advance warning signs

- appropriate speed limit signs
- pavement marking across carriageway
- lighting
- flashing lights
- appropriate run-out areas.

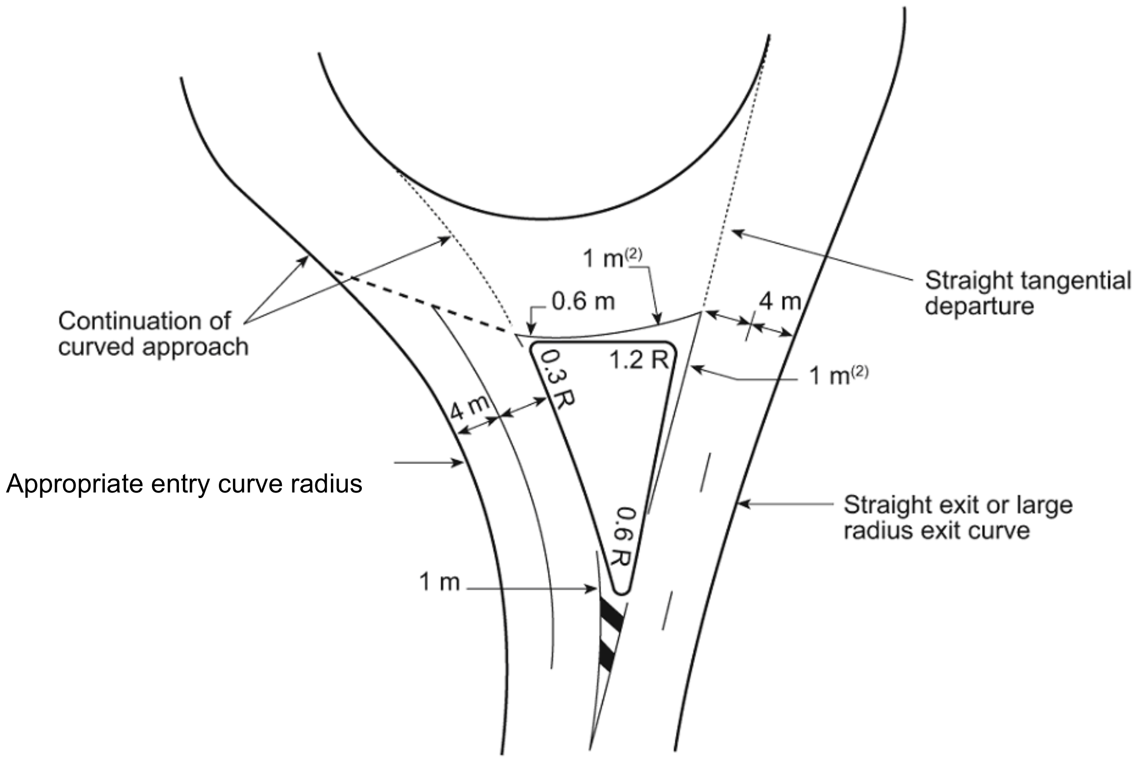
However, the effectiveness of all these treatments is very sensitive to the wider context of the intersection and relatively unknown. It is prudent for designers to monitor these types of treatments and be prepared to modify, add or remove treatments if necessary.

Where approach (operating) speeds will be greater than 60 km/h, use of vertical deflections (i.e. raised platforms or speed humps) to slow vehicles down, is not currently advised for roundabouts.

Figure 4.3: Examples of typical roundabout approaches and entries



(a) Typical rural roundabout design (with high speed approach roads)



(b) Typical arterial urban roundabout

1 *To obtain length of painted treatment plus the traffic island refer to Table 5.2 of AGRD Part 4A.*
2 *Offsets are for illustrative purposes. Refer to Section 10 of AGRD Part 4A for guidance on the appropriate offsets for various approach speeds.*

Use of approach reverse curves

There are two reasons for using reverse curves on approaches:

- to gradually reduce speed of vehicles in high-speed areas (≥ 80 km/h), as discussed in the previous section
- to improve the approach alignment onto the roundabout.

Approach reverse curves should be designed using the Operating Speed Model to predict 85th percentile speeds on each curve.

The following criteria are especially applicable for using approach reverse curves to reduce the speed of vehicles in high-speed areas.

It is considered that approach reverse curves:

- work best on single-lane approaches but also performs well on two-lane approaches (however, the appropriateness of these curves on approaches with more than two lanes is questionable)
- are undesirable on downhill approaches greater than 3% longitudinal slope
- should be visible (each approach curve and the central island) to drivers from before the first approach curve.

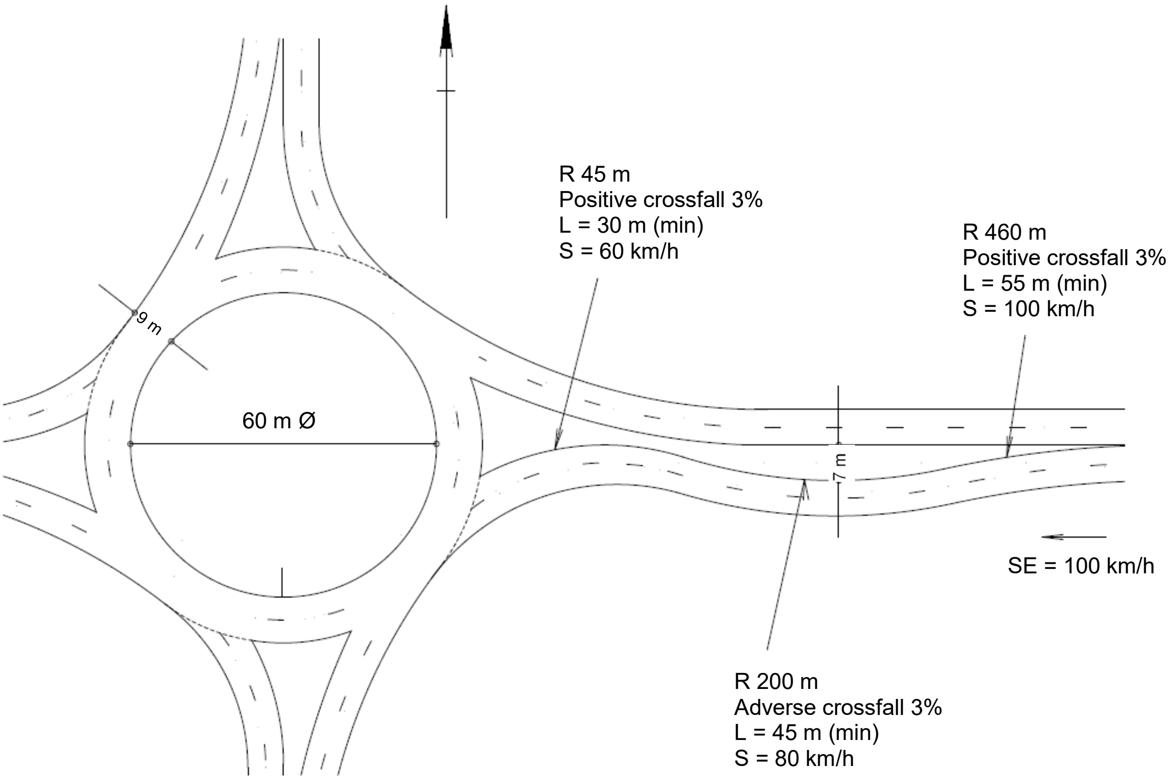
The maximum decrease in speed between successive reverse curves should be limited to 20 km/h.

Speeds generated by the Operating Speed Model will often show that excessive superelevation and/or rates of rotation on one or more curves will result, if strictly using the design criteria in accordance with AGRD Part 3. However, in practice only 2.5 to 3% superelevation is generally used on these curves and/or adverse crossfall can be applied. The use of these superelevation and crossfall values means that the limiting curve speed may be exceeded on some or all of the approach curves/entry curve. This is no different to what occurs for a single-entry curve after a horizontal straight in a high-speed area.

Some jurisdictions may have a preference on the adoption of adverse crossfall as part of a reverse curve approach treatment, and the relevant jurisdiction should be consulted prior to the commencement of design.

An example outlining the intent of this treatment using adverse crossfall on the second approach curve is shown in Figure 4.4.

Figure 4.4: An example roundabout in a high-speed rural environment – using reverse curves



Notes:
SE = Approach speed prior to entry curve/s (km/h).
R = Curve radius (m).
L = Length of curve at entry (m).
S = Speed on the curve at entry (km/h).

Source: Department of Main Roads (2006).

Approach reverse curves should be designed in accordance with AGRD Part 3 and may involve:

- the use of short horizontal straights between each curve (most desirable) to obtain positive superelevation on each curve (if used), to reduce sudden steering movements and to provide more time for drivers to react to each successive curve. Typically, this case is covered by cases 3B, 4A and 4B shown in Appendix E of AGRD Part 3
- the transition of superelevation within reverse circular curves (in constrained situations) where it is not possible to incorporate short horizontal straights. Typically, this case is covered by cases 3A and 3B shown in Appendix E of AGRD Part 3. However, such treatment may reduce the stability of heavy vehicles and so consideration should be given to the use of alternative in these cases
- the adoption of an increase in curve radius, where adverse crossfall is proposed (when compared with a positive crossfall solution) to accommodate an appropriate side friction factor
- the use of appropriate curve lengths to provide for a comfortable deceleration rate between curves (i.e. 100 km/h to 80 km/h, 80 km/h to 60 km/h, etc.).

The length of each approach reverse curve should be kept as short as possible so that single vehicle crash rates are minimised. However, the curves must also be long enough to discourage most drivers from cutting across lanes and provide sufficient deceleration length between successive curves.

The radii taken by vehicles on the approach reverse curves can be significantly larger than the actual radii of the reverse curves. This particularly applies on relatively short length horizontal curves. Designers should consider what path (and associated curve radii) vehicles are likely to use. This path should be determined based on a passenger vehicle staying in its correct lane and using the following distances between the centre of the vehicle and the lane edge at the closet point through each reverse curve:

- edge line – 1.0 m
- kerbing – 1.5 m.

Blisters

Blisters may be used at existing sites in low-speed urban areas. They are typically used on wide approaches that have on-road parking and involve the extension of the kerb and linemarking to create entry curvature (Figure 4.17).

For further information on approach and entry treatments refer to the Austroads *Guide to Road Safety Part 3: Safe Speed* (AGRS Part 3) (Austroads 2021b) and the Austroads *Guide to Traffic Management Part 5: Link Management* (AGTM Part 5) (Austroads 2020a).

4.5.3 Maximum Entry Path Radius

Maximum entry path radii to be used at one and two-lane roundabouts are given in Table 4.2. The criteria given in this table must be obtained on each entry leg of the roundabout.

The values given in the table should be used whenever possible as they will generally produce lower overall crash rates than the absolute values will. The maximum entry path radii should be used in conjunction with the minimum central island radii from Table 4.1. Avoid the use of excessively small corner kerb radii when using the values in Table 4.2.

The methods of construction of the entry path radii are given in this section. For a single-lane entry, one entry path is drawn. The maximum radius of this entry path must be in accordance with the single-lane entry criteria in Table 4.2.

For a two-lane entry, two entry paths are drawn: ‘staying in correct lane’ and ‘cutting across lanes’. The maximum radii of each of these entry paths must be in accordance with the criteria in Table 4.2. These criteria are to ensure that adequate geometry is provided to discourage motorists against completely cutting across entry lanes, minimising the likelihood of sideswipe crashes.

Table 4.2: Maximum entry path radii for one and two-lane roundabouts

Desired driver speed on the leg prior to the roundabout (km/h)	Maximum entry path radius (m)[5]	
	Single-lane entries[1] Two-lane entry – staying in correct lane[2]	Two-lane entry – cutting across lanes[3]
≤ 40	≤ 55	1.9 x actual entry path radius when staying in correct lane[4]
50		1.8 x actual entry path radius when staying in correct lane[4]
60		1.6 x actual entry path radius when staying in correct lane[4]
70		1.5 x actual entry path radius when staying in correct lane[4]
80		1.5 x actual entry path radius when staying in correct lane[4]
≥ 90		1.5 x actual entry path radius when staying in correct lane[4]

1 *Construction of the entry path of a single-lane entry for roundabouts comprising one or two circulating lanes is given in Figure 4.5.*
2 *Construction of the entry path of a two-lane entry – staying in the correct lane for a two-lane roundabout is given in Figure 4.6.*
3 *Construction of the entry path of a two-lane entry – cutting across lanes for a two-lane roundabout is given in Figure 4.7.*
4 *Radius of the entry path for drivers staying in the correct lane as determined in Figure 4.6.*
5 *Extended design domain (EDD) values for the design of the entry path radii for one and two-lane roundabouts are provided in Appendix E.*

The criteria in Table 4.2 and the methods of construction of the vehicle paths are based on limiting the values of particular roundabout safety parameters developed in the study by Arndt and Troutbeck (1998), (Appendix B). Development of these criteria is documented in Arndt (2008). An alternative to manually drawing vehicle paths and checking the maximum entry radii criteria in Table 4.2 is to use the roundabout program ARNDT. The latter also has the advantage of checking all of the roundabout safety parameters listed in Arndt and Troutbeck (1998). This program is discussed in Appendix B.

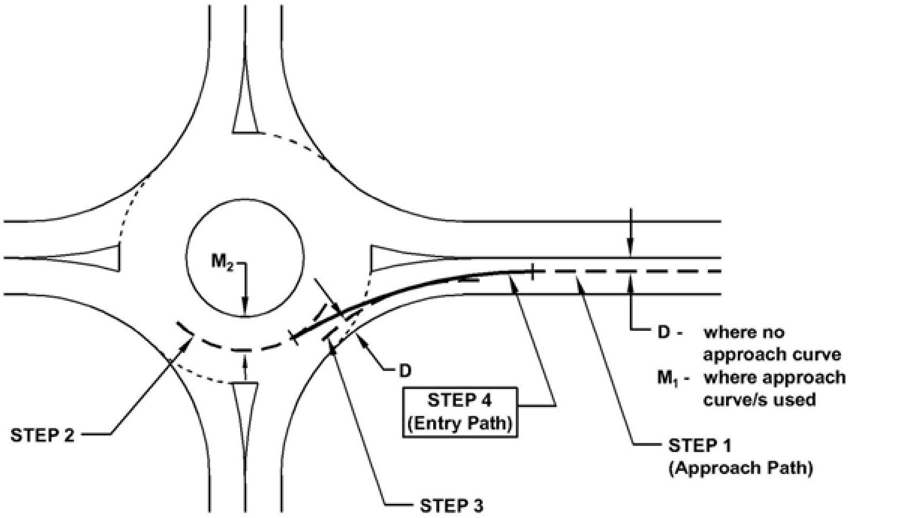
Single-lane entries

The method of construction of the entry path for single-lane entries is given in Figure 4.5. This method applies to single-lane entries on roundabouts comprising one or two circulating lanes. Steps to construct the entry path are:

- Step 1 – Where no approach curve/s is used, draw a line parallel to the right edge of the approach lane at an offset 'D' prior to the entry curve. This line is the approach path. Where an approach curve/s is used, draw this line along the last approach curve in the direction of travel at an offset of 'M_1'.
- Step 2 – Draw a curved line parallel to the edge of the central island at an offset 'M_2'. For an elliptical/oval/oblong roundabout the line may comprise multiple radii.
- Step 3 – Draw a curved line parallel to the left edge of the entry lane at an offset 'D'.
- Step 4 – Draw the entry path. This is a circular curve drawn tangentially to the lines constructed in Steps 1, 2 and 3. This path approximates the path taken by passenger car drivers on single-lane roundabout entries.

The radius of the entry path drawn in Step 4 must be no greater than the values for single-lane entries given in Table 4.2. If the measured radius exceeds the criteria, tighten the entry curve, relocate the approach leg, and/or increase the roundabout size to reduce the entry path radius to the required limit.

Figure 4.5: Construction of the entry path of a single-lane entry



D = 1.5 m when measuring from a road centreline or kerb face, 1.0 m when measuring from an edge line.
M_1 = Half the width of the approach lane.
M_2 = Half of the width of the circulating carriageway.

Source: Department of Main Roads (2006).

Two-lane entries – staying in correct lane

The method of construction of the entry path for two-lane entries for drivers staying in the correct lane is given in Figure 4.6.

The vehicle path is drawn in the right entry lane and the inner circulating lane. Steps to construct the entry path for drivers staying in the correct lane are:

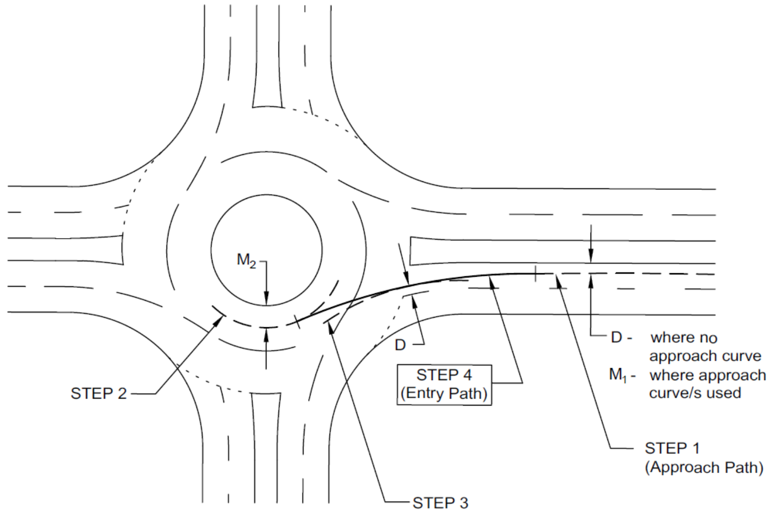
- Step 1 – Where no approach curve/s is used, draw a line parallel to the right edge of the right approach lane at an offset 'D' prior to the entry curve. This line is the approach path. Where an approach curve/s is used, draw this line along the last approach curve in the direction of travel at an offset of 'M_1'.
- Step 2 – Draw a curved line parallel to the edge of the central island at an offset 'M_2'. For an elliptical/oval/oblong roundabout the line may comprise multiple radii.
- Step 3 – Draw a curved line parallel to the left edge of the right entry lane at an offset 'D'.
- Step 4 – Draw the entry path for drivers staying in the correct lane. This is a circular curve drawn tangentially to the lines constructed in Steps 1, 2 and 3. This path approximates the entry path taken by a passenger car driver who completely cuts across lanes on a two-lane roundabout.

The radius of the entry path for drivers staying in the correct lane, as drawn in Step 4, must be no greater than the values given in Table 4.2 for a 'two-lane entry – staying in correct lane'. If the measured radius is exceeded, tighten the entry curve, relocate the approach leg, and/or increase the roundabout size to reduce the entry path radius to the required limit.

If a circular curve cannot be drawn according to the criteria in Step 4, appropriate entry curvature has not been provided.

Similarly, the outer (or left entry) lane should be checked using the same method.

Figure 4.6: Construction of the entry path of a two-lane entry – staying in the correct lane



D = 1.5m when measuring from a road centreline or kerb face, 1.0m when measuring from a lane line or edge line.
M_1 = Half the width of the right approach lane.
M_2 = Half the width of the inner circulating lane.

Source: Department of Main Roads (2006) .

Two-lane entries – cutting across lanes

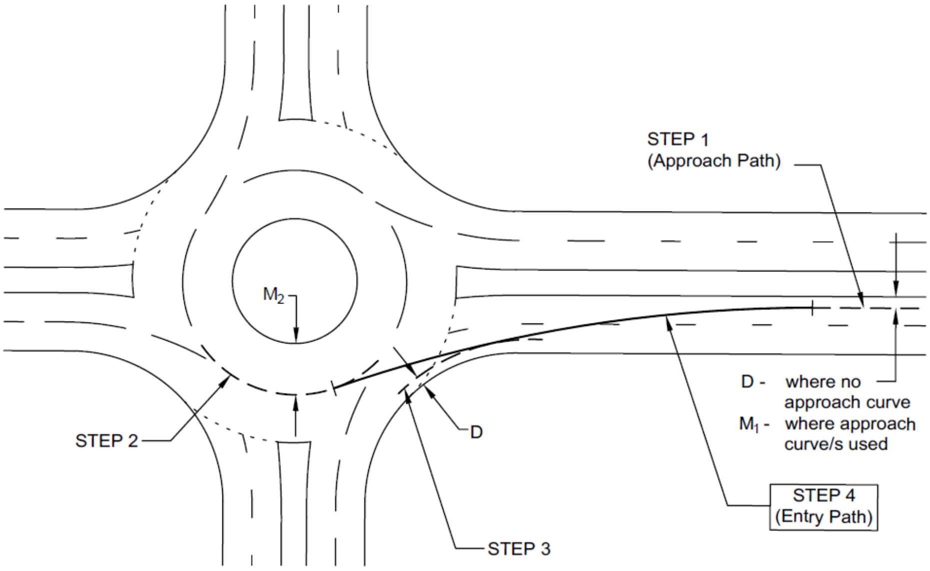
The method of construction of the entry path for two-lane entries for drivers cutting across lanes is given in Figure 4.7. Steps to construct the entry path for drivers cutting across lanes are:

- Step 1 – Where no approach curve/s is used, draw a line parallel to the right edge of the right approach lane at an offset 'D' prior to the entry curve. This line is the approach path. Where an approach curve/s is used, draw this line along the last approach curve in the direction of travel at an offset of 'M_1'.
- Step 2 – Draw a curved line parallel to the edge of the central island at an offset 'M_2'. For an elliptical/oval/oblong roundabout the line may comprise multiple radii.
- Step 3 – Draw a curved line parallel to the left edge of the left entry lane at an offset 'D'.
- Step 4 – Draw the entry path for drivers cutting across lanes. This is a circular curve drawn tangentially to the lines constructed in Steps 1, 2 and 3.

The radius of the entry path drawn in Step 4 must be no greater than the radius of the entry path for drivers staying in the correct lane (determined in Figure 4.6) multiplied by the appropriate factor in Table 4.2 for a 'two-lane entry – cutting across lanes'. If the measured radius is exceeded, lengthen the entry curve, relocate the approach leg, and/or increase the roundabout size to reduce the entry path radius (cutting across lanes) to the required limit.

If a circular curve cannot be drawn according to the criteria in Step 4, appropriate entry curvature has not been provided.

Figure 4.7: Construction of the entry path of a two-lane entry – cutting across lanes



D = 1.5m when measuring from a road centreline or kerb face, 1.0m when measuring from a lane line or edge line.
M_1 = Half the width of the right approach lane.
M_2 = Half the width of the inner circulating lane.

Source: Department of Main Roads (2006).

4.5.4 Splitter Islands

Kerbed splitter islands should be provided on all roundabouts as they:

- assist in controlling entry speed
- guide traffic onto the roundabout
- deter right-turners from taking dangerous 'wrong way' short cut movements through the roundabout
- provide shelter for pedestrians.

An exception is very small roundabouts in local residential access roads where insufficient space is available for raised traffic islands, in which case painted islands may be used. It should also be noted that if a compact design approach is adopted the splitter islands will not tend to guide traffic around the roundabout, but rather directly towards the central island.

Where a splitter island provides shelter for pedestrians and cyclists, the approach speeds may determine whether additional protection is required for the pedestrians.

Splitter island kerbing should be semi-mountable and light-coloured or painted white with reflective paint. Splitter islands should be designed to direct vehicles onto the roundabout so that the vehicle path is smooth, but at an angle which affords the drivers comfortable sighting of approaching traffic, i.e. a good observation angle. The right-hand edge of the entry curve, where it turns into the circulating carriageway, should generally be tangential to the central island as shown in Figure 4.3. However, in some cases the projection of the right-hand edge of the entry curve may be permitted to:

- pass through a point about 1.5 m offset to the left of the central island to accommodate the swept path of heavy vehicles on the pavement, i.e. outside rear trailer wheels
- be aimed at a point in the central island; applicable where the roundabout is used primarily by cars and cyclists and it is desired to further reduce entry speeds so that drivers have a better opportunity to scan the roundabout for cyclists.

On urban arterial road roundabouts, the kerbed splitter island should be of sufficient size to shelter a pedestrian with a pram or a bicycle (at least 2.4 m wide at the crossing point) and be highly visible to approaching traffic. Splitter islands at arterial road roundabouts should desirably have a reasonably large area, e.g. 40 m^2. However, where space is constrained at local street roundabouts, a minimum area of 8 to 10 m^2 may be provided.

For roundabout approaches on local roads that carry a relatively low volume of traffic, the general minimum area of kerbed splitter islands should be 5 to 8 m^2.

In high-speed areas the splitter island should be long enough to:

- give early warning to drivers that they are approaching an intersection and must slow down
- enable drivers to easily recognise the degree of curvature on the right side of the entry; it is desirable that this kerb cuts across the prolongation of the approach lane/s (Figure 4.3) so that drivers perceive a physical constraint at the entry.

The splitter island and its approach pavement markings should preferably extend back to a point where drivers would be expected to start to reduce their speed. As a guide, the length of the overall treatment in a high-speed rural situation (start of approach linemarking to holding line) should be equal to the distance required to decelerate from the approach speed to a stop (Figure 4.3 (a) and Table 5.2 of AGRD Part 4A. For example, in a 100 km/h environment an overall length of 155 m would be required, resulting in a splitter island about 50 to 60 m long.

The lateral restriction and funnelling provided by the splitter island encourages speed reduction as vehicles approach the entry point. In the case of compact roundabout designs, slower speeds will be further encouraged by the straight edges of the splitter island guiding vehicle drivers directly towards the central island. The kerb should desirably also be placed on the left-hand side of the approach road for the length of the splitter island to ensure that vehicle paths into the roundabout are constrained to an appropriate entry speed.

Landscaping and road furniture within traffic islands and medians should not impede visibility of the roundabout or obstruct a driver's sight lines. Adequate clear zones should also be provided to roadside hazards. Hazards within a clear zone should be removed, treated or shielded with a barrier.

4.6 Circulating Carriageway

4.6.1 Design Vehicle and Vehicle Swept Paths

The selection of an appropriate design vehicle (and checking vehicle) is discussed in *Design Vehicles and Turning Path Templates Guide* (AP-G34-23) (Austroads 2023a). As with other types of intersection, the design vehicle and consequently the swept path requirements may be different for the various paths through a roundabout. For example, the straight-through movement at a particular roundabout may have to cater for 25 m B-doubles whereas the left and right-turning movements may only need to cater for single unit trucks. This can occur because:

- Particular types of heavy vehicles can be restricted to certain routes or from entering certain areas and consequently their turning movements at a roundabout are restricted.
- The volumes of a particular type of heavy vehicle are extremely low on particular turning movements. In this case encroachment areas may be provided, which allow a smaller width of circulating carriageway to be used.

Because travel through roundabouts involves complex reverse-turn movements, particular care is needed in the use of simple turning path templates, – refer to AP-G34-23 to achieve a satisfactory layout. A more accurate result is obtained by using a computer plot of the design vehicle’s swept path on an assumed travel path through the critical turning movements. Computer programs such as VPATH, AUTOTURN, and AUTOTRACK are examples. These programs may also be used to check the ability of a roundabout to cater for any checking vehicles or over-dimensional vehicles which may need to be accommodated.

4.6.2 Width of Circulating Carriageway

General

The width of the circulating carriageway depends on several factors, the most important of which are the number of circulating lanes and the radius of vehicle swept paths within the roundabout.

Table 4.3 and Table 4.4 provide an initial guide to the circulating roadway width that can be used for single-lane and two-lane roundabouts respectively and are therefore used to establish draft layouts. However, the widths need to be checked by using a plot of the design vehicle’s swept path (e.g. using VPATH) and an assumed travel path through the critical turning movements or vehicle templates. This check is required because the widths in Table 4.3 may not be sufficient for all possible combinations of roundabout geometry and turning movements. In addition, if the design vehicle is only travelling straight through the roundabout, the widths may be unnecessarily large.

Single-lane roundabouts

The circulating carriageway width of single-lane roundabouts should cater for the movement of the largest vehicle normally expected to use the roundabout, i.e. the design vehicle. An offset of 0.5 m from each edge of the vehicle swept path to the lane edge or line of kerb should be provided. Circulating carriageway widths initially required to cater for one heavy vehicle turning right using the above offsets are shown in Table 4.3.

Table 4.3: Initial selection of single-lane roundabout circulating carriageway widths

Central island radius[1] (m)	Width required for design vehicles[2] (m)				
	12.5 m single unit truck	19 m semi-trailer	25 m B-double	Type 1 road train	Type 2 road train
5	–	9.2	–	–	–
6	–	8.9	9.9	–	–
8	6.7	8.4	9.4	10.9	–
10	6.3	8.0	8.9	10.4	12.4
12	5.9	7.6	8.5	9.9	11.9
14	5.8	7.2	8.1	9.5	11.4
16	5.6	7.0	7.8	9.1	10.9
18	5.4	6.7	7.5	8.7	10.5
20	5.2	6.5	7.2	8.4	10.1
23	5.1	6.2	6.8	8.0	9.6
26	4.9	5.9	6.6	7.6	9.2
30	4.8	5.7	6.2	7.2	8.6
35	4.8	5.4	5.8	6.7	8.0
40	4.8	5.2	5.6	6.4	7.6
45	4.8	5.0	5.4	6.1	7.2
50	4.8	4.9	5.2	5.9	6.9
60	4.8	4.8	5.0	5.5	6.3
70	4.8	4.8	4.8	5.2	6.0
80	4.8	4.8	4.8	5.0	5.7

1 *Radius used for the purpose of determining vehicle path.*
2 *The widths given in this table are based on right-turning vehicle paths with a 0.5 m offset to the central island and a 0.5 m offset to the outer edge of the circulating carriageway. Widths are based on the truck turning right in the lane adjacent to the central island.*

Two-lane roundabouts

The circulating carriageway width of two-lane roundabouts needs to cater at least for the movement of the largest vehicle normally expected to use the roundabout (i.e. the design vehicle) turning on the inside of a passenger car, i.e. the large vehicle adjacent to the central island. In this case a clearance of 1.0 m should be provided between the swept paths of vehicles travelling in the same direction, and a distance of 0.5 m from the edge of the vehicle swept paths to the lane edges/kerbs should be provided.

Circulating carriageway widths initially required to cater for one heavy vehicle turning right alongside a passenger car using the offsets described above are shown in Table 4.4. The values in the table are nominally 3.0 m greater than those given for single-lane roundabouts. The value of 3.0 m allows for a 2 m wide passenger car and an additional 0.5 m clearance on either side. The widths given in Table 4.4 should be checked by using computer plots or templates to ensure that adequate but not excessive pavement width is provided.

Where a site has a high volume of heavy vehicles it may be necessary to design for two heavy vehicles turning alongside each other, e.g. a semi-trailer and a single unit truck/bus. In some situations (e.g. intersections serving seaports) it may be necessary to design for two semi-trailers turning together. Austroads turning templates do not include these variations and therefore an assessment should be made using individual templates and the recommended clearances, or by using computer software package (Section 5, Austroads *Guide to Road Design Part 4: Intersections and Crossings: General* (AGRD Part 4) (Austroads 2023b)).

Table 4.4: Initial selection of two-lane roundabout circulating carriageway widths

Central island radius(1)(m)	Width required for design vehicles(2)(m) (Dual turn – design vehicle plus a car)				
	12.5 m single unit truck	19 m semi-trailer	25 m B-double	Type 1 road train	Type 2 road train
8	9.7	–	–	–	–
10	9.3	11.0	–	–	–
12	9.0	10.6	11.5	–	–
14	8.8	10.2	11.1	12.5	–
16	8.6	10.0	10.8	12.1	13.9
18	8.4	9.7	10.5	11.7	13.5
20	8.2	9.5	10.2	11.4	13.1
23	8.1	9.2	9.8	11.0	12.6
26	7.9	8.9	9.6	10.6	12.2
30	7.7	8.7	9.2	10.2	11.6
35	7.6	8.4	8.8	9.7	11.0
40	7.5	8.2	8.6	9.4	10.6
45	7.4	8.0	8.4	9.1	10.2
50	7.3	7.9	8.2	8.9	9.9
60	7.2	7.7	8.0	8.5	9.3
70	7.1	7.5	7.8	8.2	9.0
80	7.0	7.4	7.6	8.0	8.7

1 *Radius used for the purpose of determining vehicle path.*
2 *The widths in this table are nominally 3.0 m greater than the widths given for single-lane roundabouts for the reasons given in the main text.*

There are cases for which the use of the values of circulating carriageway widths in Table 4.3 and Table 4.4 may lead to inadequate entry curvature being achieved. In these cases, where it is uneconomical to increase the diameter of the central island, it is preferable to reduce the circulating carriageway widths to provide adequate entry curvature. This will result in the design vehicle having to encroach onto an over-run apron in the central island. These encroachment areas (discussed in Section 4.6.3) will need to be specially constructed and a typical cross-section is shown in Figure 4.11.

Application of vehicle swept paths

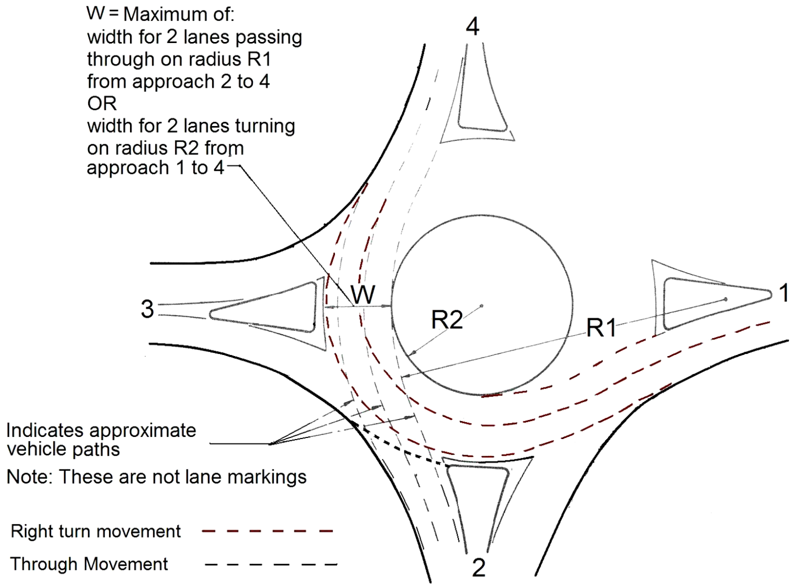
The circulating roadway width of a roundabout may have to cater for one, two or three vehicles travelling straight through, or two vehicles turning right as depicted in Figure 4.8.

The widths in Table 4.4 assume that there is only one design vehicle in any group turning simultaneously and this will generally be the case, e.g. freight routes or roads serving sea ports. For the roundabout in Figure 4.8 the width W should be the larger of:

- two lanes turning right from Leg 1 on radius R2; it is recommended that roundabouts are not used where it is necessary to provide for three lanes of right-turners
- two lanes travelling through the roundabout side by side on radius R1.

Designers will have to estimate R1 from the initial layout. The determination of R1 is an iterative process in that designers have to assume a layout, plot the swept paths for the through movement, and determine the radius of the swept path. The value of R1 can then be used to verify that dimension 'W' is adequate.

Figure 4.8: Application of circulating carriageway widths to a multilane roundabout



It can be seen from Figure 4.8 that the swept paths of the design vehicle for the through movement and the double right-turn movement do not necessarily coincide within the circulating width W. While it is desirable that lane marking within the circulating carriageway enable both through and right-turning design vehicles to remain within the marked lanes, this may not always be possible, particularly on smaller roundabouts.

When designing for buses and particularly low-floor buses, designers should be aware of the characteristics of these vehicles, particularly the relatively large front overhang (Figure 4.9). Where it is required to narrow the circulating carriageway to control the speed of smaller vehicles (for example passenger cars), it may be necessary to accommodate buses by using encroachment areas (Section 4.6.3 and Figure 4.11). Desirably, the swept paths of buses should be accommodated within the pavement area. The following measures should be considered when designing for buses at all roundabouts on both local and arterial roads:

- Semi-mountable kerbs should be used so that drivers and vehicles are not adversely affected should they mount the kerb. Wherever possible, barrier kerbs and bluestone kerbs (i.e. higher kerbs and rough stone) should be avoided.
- Areas immediately behind the kerbs should have no raised objects or hazards (e.g. poles, signs, landscaping rocks, etc.) in case the front overhang of the vehicle has to traverse the area for any reason.
- If, for any reason, an encroachment area is required, the kerb should be fully mountable so that the comfort of passengers is not compromised.

Figure 4.9: Front overhang on low-floor bus

Source: VicRoads (1999).

Figure 4.10: Areas behind kerbs should be kept clear of objects

Source: VicRoads (1999).

4.6.3 Encroachment Areas

Intersections, including roundabouts, are designed to provide for all movements by a chosen design vehicle to occur within the pavement area. The design vehicle may be very large on routes that carry a significant volume of freight; on some routes it may be necessary to adopt a road train as the design vehicle. Where the design vehicle is smaller (e.g. B-double) it may be necessary for the intersection to accommodate an occasional heavy vehicle that is larger than the design vehicle, i.e. a checking vehicle (Austroads 2023a).

In some cases, a road train may be the design vehicle, but it may be impractical to accommodate its swept path on the circulating pavement and also meet the required design principles for maximum entry path radii. In such cases, there is usually no option but to provide for road trains to use encroachment areas. These areas may be constructed as a fully mountable raised area or be flush with the circulating pavement, e.g. painted area or contrasting pavement surfacing.

In cases where the volumes of a particular heavy vehicle type (checking vehicle or over-dimensional vehicle) are extremely low on particular turning movements, it may be appropriate to provide encroachment areas (paved areas behind the kerbs) which allow a smaller width of circulating carriageway to be used. Over-dimensional vehicles are vehicles that have greater than the maximum legal dimensions and may be permitted to operate on major arterial routes under specific permit conditions, which usually require the use of an escort vehicle. Roundabouts on major arterial routes need to cater for these vehicles, and because their size can vary greatly, it is not essential that such vehicles be able to traverse the intersection without encroaching onto the central island area and/or the approach splitter islands. However, care must be taken to ensure encroachment areas should not be included in areas used by pedestrians, such as pedestrian paths. Encroachment areas should not be within pedestrian storage areas such as within splitter islands, median walkthroughs and kerb ramps.

It is desirable that all roundabouts on bus routes be designed so that buses are able to perform all necessary movements on the road pavement. However, at existing intersections where a roundabout is to be provided for road safety reasons and space is restricted, there may be no alternative than to design it on the basis of the bus having to travel on an encroachment area at the edge of the central island. This is likely to be the case where larger buses such as low-floor buses, which have a large front overhang, have to be accommodated at the intersection. Figure 4.9 and Figure 4.10 show a low-floor bus manoeuvring through a roundabout at the intersection of two local collector roads.

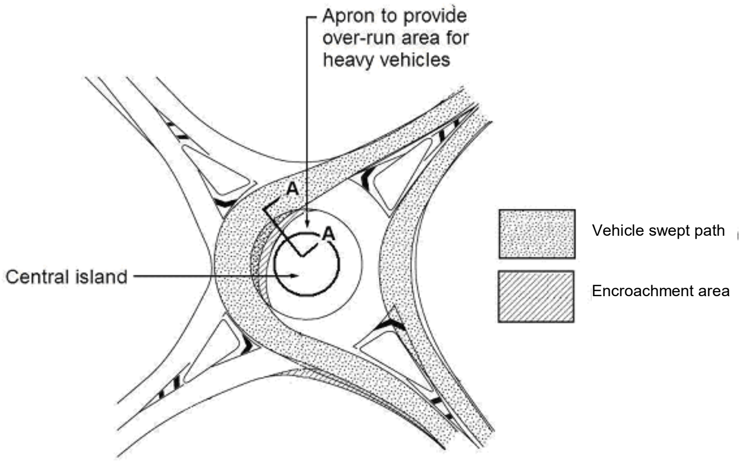
Encroachment areas should therefore:

- be constructed of appropriate load-bearing pavement
- have semi-mountable or fully mountable kerbs
- not have drainage pits located within them or, if this is not practicable, have suitably reinforced pits to carry the heavy wheel loads
- not accommodate road furniture.

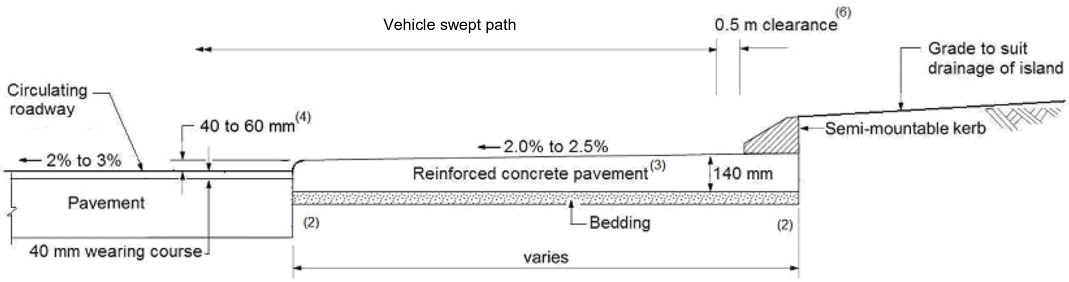
Figure 4.11 illustrates encroachment areas that may be provided to cater for a checking vehicle or an over-dimensional vehicle that is turning right or left at a roundabout. Appropriate delineation is required to discourage use of the encroachment areas by passenger vehicles. This may be accomplished by adding pavement markings around the encroachment area or by using a pavement in the encroachment area that contrasts with the pavement in the circulating lane.

From a safety perspective, particularly for motorcyclist and cyclist safety, implementing a larger roundabout to accommodate all vehicle movements on the circulating pavement is preferred over a small roundabout with raised aprons. However, it is recognised that this is not always achievable due to the larger footprint required, which may make it implausible for many brownfield sites. All roundabouts should have road lighting and the provision of lighting in accordance with AS/NZS 1158 becomes even more important, especially to motorcyclists, if profiled encroachment areas are incorporated into the design.

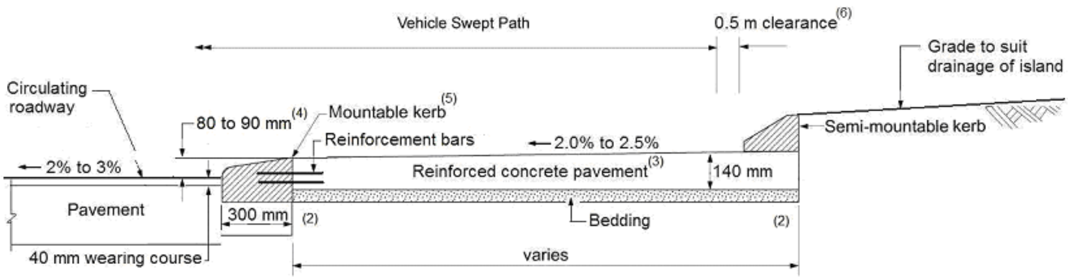
Figure 4.11: Typical encroachment area detail at a roundabout



PLAN VIEW



Section AA for type A encroachment area(1)



Section AA for type B encroachment area(1)

1 *Alternative profiles that discourage drivers of passenger cars from mounting raised area that is designed to enable relatively smooth passage by heavy vehicles.*
2 *Subsoil drainage may be required in these zones.*
3 *Reinforced concrete pavement. Thickness and reinforcement designed for appropriate loading. Alternative surfacing may be used on top of the pavement.*
4 *Height may vary within this range depending on jurisdictional requirements.*
5 *Mountable kerb to jurisdiction profile must be tied to reinforced concrete pavement to prevent differential movement. Dimensions shown are examples only.*
6 *Clearance is measured to the vehicle swept path, not to the wheel path.*

Source: Based on Department of Main Roads (2006).

4.7 Exit Curves

The exiting/circulating vehicle crash rate at any particular exit point of multilane roundabouts is predominantly related to the potential relative speed of exiting and circulating vehicles. For this reason, the exit from the roundabout should be designed to be as easy as practicable for drivers to negotiate.

After having been slowed down by the entry curve(s) and circulating on a roundabout, drivers should be able to accelerate from the circulating roadway through the exit. Therefore, the exit should either be tangential to the central island or be designed with a relatively large radius as this limits the amount of side friction drivers use at this location, and minimises the single vehicle crash rate on the exit curve (Figure 4.3).

If using short horizontal straights between circulating carriageway and exit curves, a length of 5 m is usually sufficient to accommodate heavy vehicle dynamics.

In areas where a significant number of pedestrians crossing the exit or there is parking activity on the road beyond the exit, the exit speed should be limited by providing a smaller radius exit curve. This will maximise safety for pedestrians crossing the exit.

The exception to this is the case of urban roundabouts where it is desirable to slow exiting traffic because of pedestrians.

4.8 Entry and Exit Widths

The width of the entry should be able to accommodate the swept path of the entering design vehicle. However, it is important that the entry is not any wider than necessary, as excessive entry widths can make it difficult for designers to achieve adequate speed reduction at the entries to roundabouts.

On arterial roads the swept path of the design vehicle must be able to be accommodated within the appropriate traffic lane on the entry with adequate clearance to kerbs. It is desirable for single-lane entries to be at least 5.0 m between kerbs (i.e. line of kerb) in order to provide sufficient width for traffic to pass a disabled vehicle.

On local streets entry lane widths should be designed primarily to enable access by the design vehicle. However, on small roundabouts a lesser width may be used, in which case consideration should be given to the provision of semi-mountable kerbs and trafficable areas behind the kerbs, or other measures to allow access by service vehicles.

There are cases in which the use of adequate entry lane widths for large vehicles will lead to inadequate entry curvature, e.g. providing for road trains on rural roundabout approaches. In these cases, it is preferable to reduce the entry lane widths to provide adequate curvature and provide encroachment areas (Section 4.6.3) to cater for the movement of larger vehicles. Typical encroachment areas for this purpose are shown in Figure 4.11.

Exits at arterial road roundabouts generally have a relatively large radius to enable traffic to leave the circulating roadway as efficiently as possible. The exit width should therefore be based on the number of traffic lanes required plus any required offsets to kerbs. For arterial roundabouts where there is high pedestrian activity across exits, and for local street roundabouts, it may be desirable to provide a tighter radius on the exits to reduce exit speeds, and this may result in a wider exit to accommodate the tracking of design vehicles.

Entry and exit lane widths need to be checked for vehicle swept paths to ensure that the design vehicle is properly accommodated. Again, a more accurate result is obtained through the use of a computer plot of the design vehicle's swept path (e.g. using VPATH) on an assumed travel path through the critical turning movements.

4.9 Separation between Legs

The periphery of a roundabout, as defined by the inscribed circle diameter (Figure 2.1) is a very important element in the design of a successful roundabout. If the inscribed circle is too small, it is difficult to accommodate well-designed entries and exits as they tend to overlap. This can lead to the curves on the corners of the roundabout being too sharp and the corner falling outside of the inscribed circle, resulting in additional unwanted pavement. On the other hand, if the inscribed circle is too large, it can result in curve reversals or excessive radii at the corners. Figure 4.12 shows examples of desirable and undesirable separation of roundabout legs.

The corner kerb radii may be smaller than the entry curve, but excessively sharp corner kerb radii should never be used as this results in minimum separation between an approach leg and the next departure leg. This produces a higher angle between the entering and circulating vehicle paths, which increases the relative speed of entering and circulating vehicles. This in turn increases entering/circulating vehicle crash rates. For this reason, it is preferable to design the entry and exit curves tangential to the outer edge of the circulating carriageway as shown in Figure 4.3.

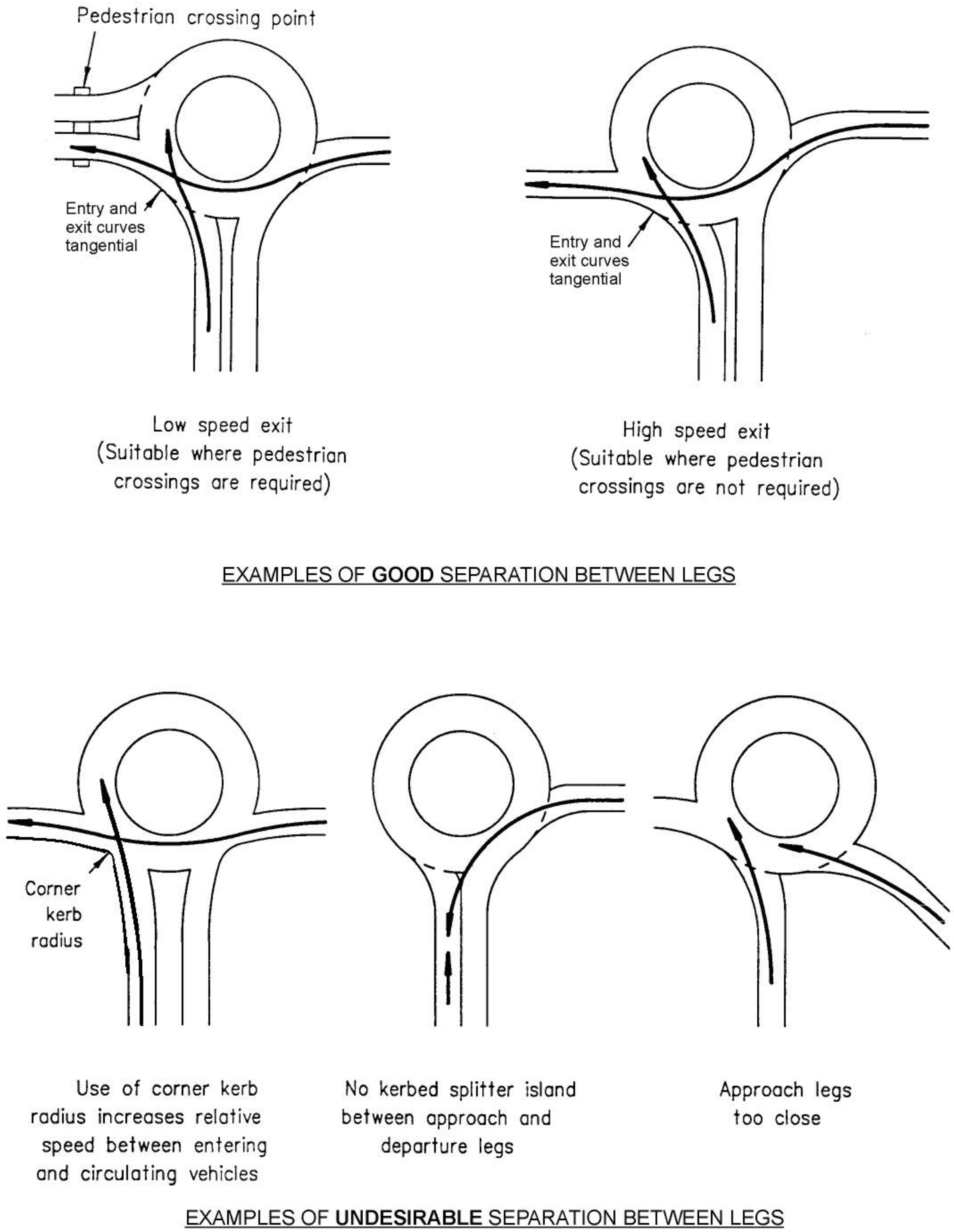
The combination of avoiding the design of sharp corner kerb radii that are substantially smaller than the approach or departure curve and maximising the width of kerbed splitter islands maximises the distance between approach and departure carriageways of a particular roundabout leg. This in turn increases the separation between legs and minimises the entering/circulating vehicle crash rate.

Additional conflicts can occur at two-lane roundabouts with the following geometry at a roundabout entry:

- two circulating lanes where a two-lane entrance is followed by a two-lane exit
- a significant distance between the two-lane entry and the next downstream exit
- both circulating lanes marked allowing departure at the next exit
- both entry lanes marked allowing circulation past the next roundabout exit.

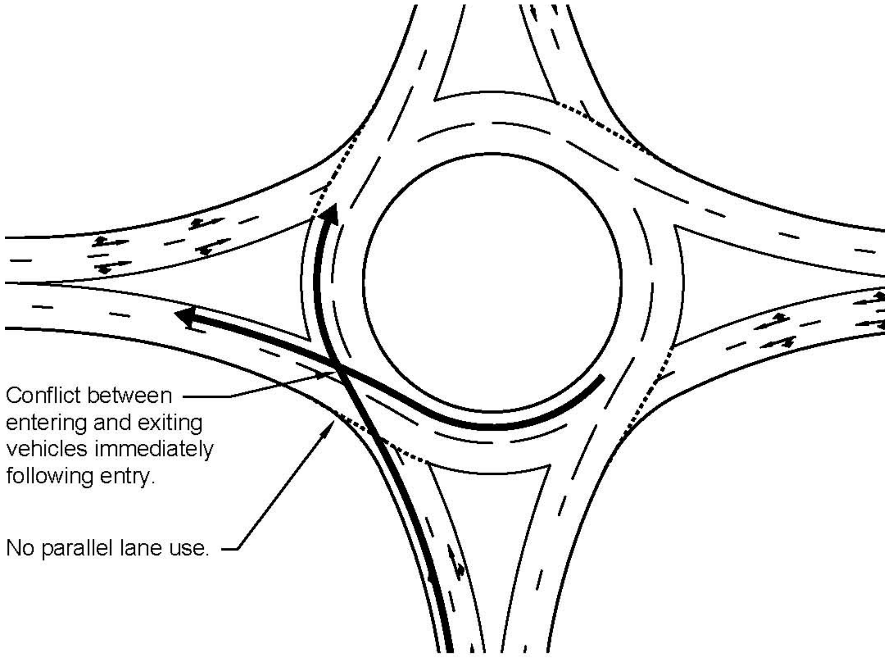
In the first diagram in Figure 4.13, an entering vehicle in the left lane, travelling around the roundabout, immediately crosses the exiting lanes after entering the roundabout. In the second diagram in Figure 4.13, an entering vehicle in the left lane, travelling around the roundabout, travels parallel to the inside lane for some distance. The entering vehicle then has to cross the exit path at the first downstream exit of a vehicle in the inner lane. In this circumstance there is an increased potential for conflict between the entering vehicle and a circulating vehicle departing at the next exit and an increase in exiting/circulating vehicle accidents is likely to occur. It is strongly suggested that roundabout geometry shown in the second diagram of Figure 4.13 not be accepted.

Figure 4.12: Examples showing desirable and undesirable separation between roundabout legs

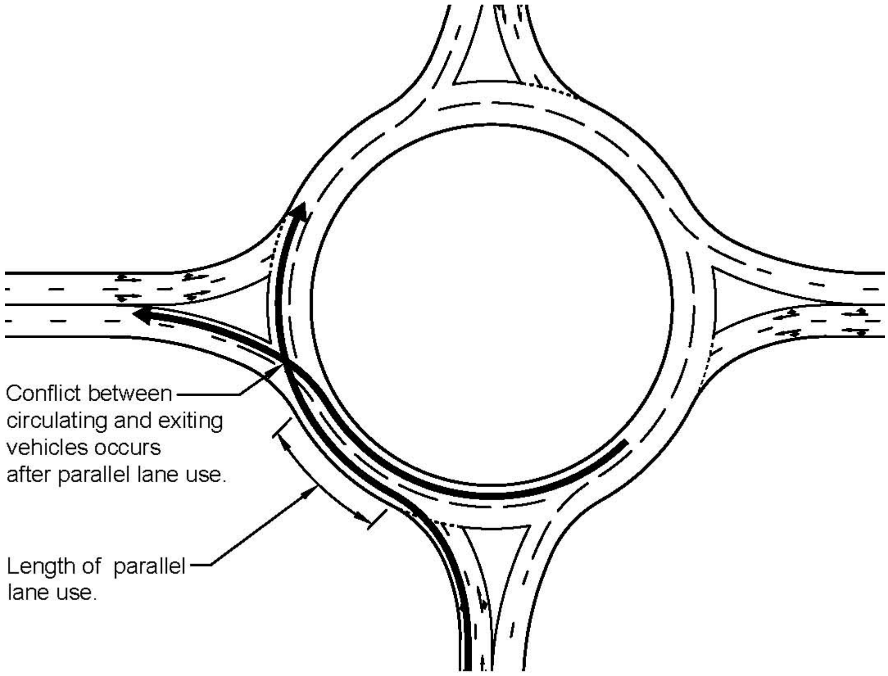


Source: Department of Main Roads (2006).

Figure 4.13: Examples showing desirable and undesirable separation between roundabout legs on multilane roundabouts



EXAMPLE OF GOOD SEPARATION BETWEEN LEGS OF MULTILANE ROUNDABOUTS



EXAMPLE OF UNDESIRABLE SEPARATION BETWEEN LEGS OF MULTILANE ROUNDABOUTS

Note: The linemarking in the second diagram is shown for clarity purposes only. In practice, this linemarking would require a vehicle entering in the left lane to exit at the next exit which is in conflict with the approach pavement arrows.

Source: Queensland Department of Transport and Main Roads (2021b) and Queensland Department of Transport and Main Roads (2021a).

4.10 Superelevation, Gradient and Drainage

4.10.1 Crossfall

Positive or adverse crossfall

As a general design practice, a maximum pavement crossfall or superelevation of 2.5 to 3% should be adopted for the circulating carriageway. Many roundabouts operate satisfactorily with an adverse crossfall of 2.5 to 3% as, at slower speeds, friction contributes to stability more so than superelevation.

An adverse crossfall or positive superelevation of 0.02 m/m may be provided if construction tolerances are tightly controlled as it would provide additional driver comfort. Further advantages of adverse crossfall are that the central island is higher and more visible to drivers approaching the roundabout, and drainage is not required in the central island. A disadvantage of adverse crossfall on the circulating carriageway, however, is that it results in higher single vehicle crashes for trucks than positive superelevation.

Positive superelevation on the circulating roadway has an advantage in reduced single vehicle truck crashes; however, a negative aspect is that the circulating roadway is sometimes hidden from the view of approaching motorists, thereby inhibiting drivers' recognition of the central island and the roundabout treatment. A further disadvantage is that vehicle occupants turning left through the roundabout may suffer discomfort as they move from positive to negative crossfall and back to positive crossfall.

The use of appropriate entry curvature in accordance with Section 4.5 will slow motorists before the roundabout so that the negative effects of either adverse crossfall or positive superelevation are minimised. Therefore, a relatively safe roundabout can be designed with either adverse crossfall or positive superelevation on the circulating roadway.

Use of a crown in the circulating carriageway

An alternative to positive or negative crossfall in one direction is to provide a crown following the centreline of a two-lane circulating roadway. This has the advantage of providing positive superelevation for vehicles, particularly trucks that are turning right through the roundabout, and consistent positive superelevation for left-turning vehicles. However, the use of a crown could cause some destabilisation to the through traffic, which would experience twists in the pavement from positive to negative to positive. If a crown is used at roundabouts, the crossfalls used should preferably not exceed 2.5% (grade change of 5% across the crown). A further disadvantage is that a crown is relatively difficult to construct on a circulating carriageway with crossfalls of 2.5%.

Roundabout radius, crossfall and heavy vehicle stability

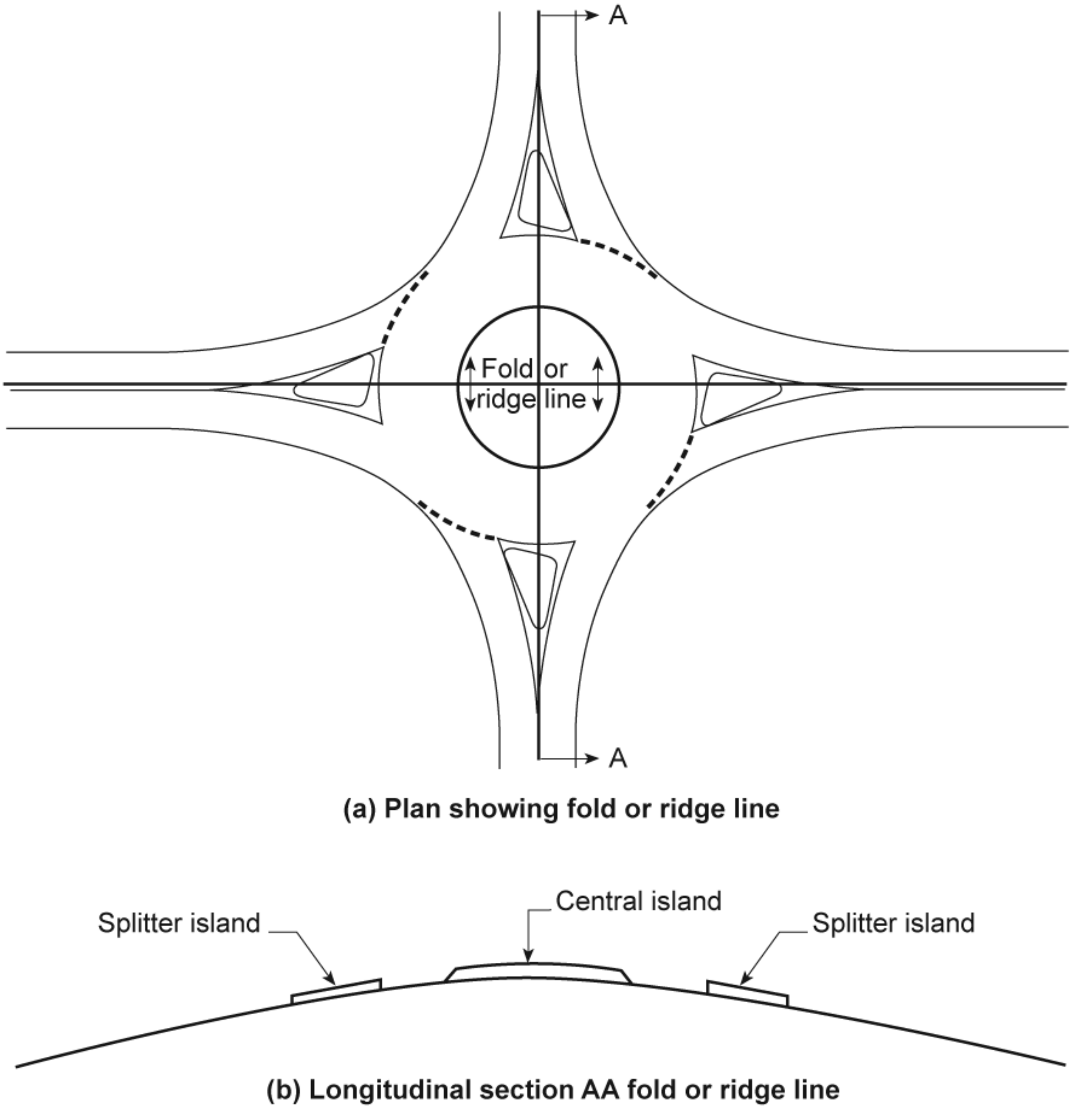
The most appropriate grading to use on a roundabout depends on the central island radius that can vary from 4 m to preferably no more than 75 m. Roundabouts with radii less than 10 m do not provide for large trucks and buses and are not suitable for use on arterial roads. However, for these small roundabouts, grades and hence crossfall on the circulating carriageway should not exceed 5%. Where the radius exceeds 40 m roundabouts can be graded as would a normal road (i.e. with positive superelevation on the circulating roadway) as there is more space in which to adequately design superelevation transitions.

The intermediate range (between 10 and 40 m) needs special attention as, at these radii, truck operating speeds are likely to be close to the critical overturning speeds for high vehicles. This potential problem is exacerbated by the adverse crossfall that is commonly used to provide good sight distance to the pavement and central island within roundabouts. Nevertheless, it is important to design roundabouts to achieve the best grading arrangement to suit each site and in particular to avoid features which could adversely affect truck stability.

Factors to consider with respect to truck stability include:

- Avoid rapid changes in crossfall which can cause instability for high heavy vehicles and their loads, i.e. a reduction in positive crossfall, a change from positive to negative crossfall or an increase in negative crossfall.
- Provide the minimum adverse crossfall within the constraints imposed by drainage and the ability to construct a minimum crossfall, i.e. 2% adverse on single-lane roundabouts and 2.5% adverse on multilane roundabouts.
- Roundabouts with a fold or ridge through the centre as shown in Figure 4.14 should be avoided. However, where the site conditions require such a grading, the maximum change of grade over the ridge should be limited to 4% and the vertical curve joining the two grades should be as long as possible.

Figure 4.14: Roundabout with fold or ridge line



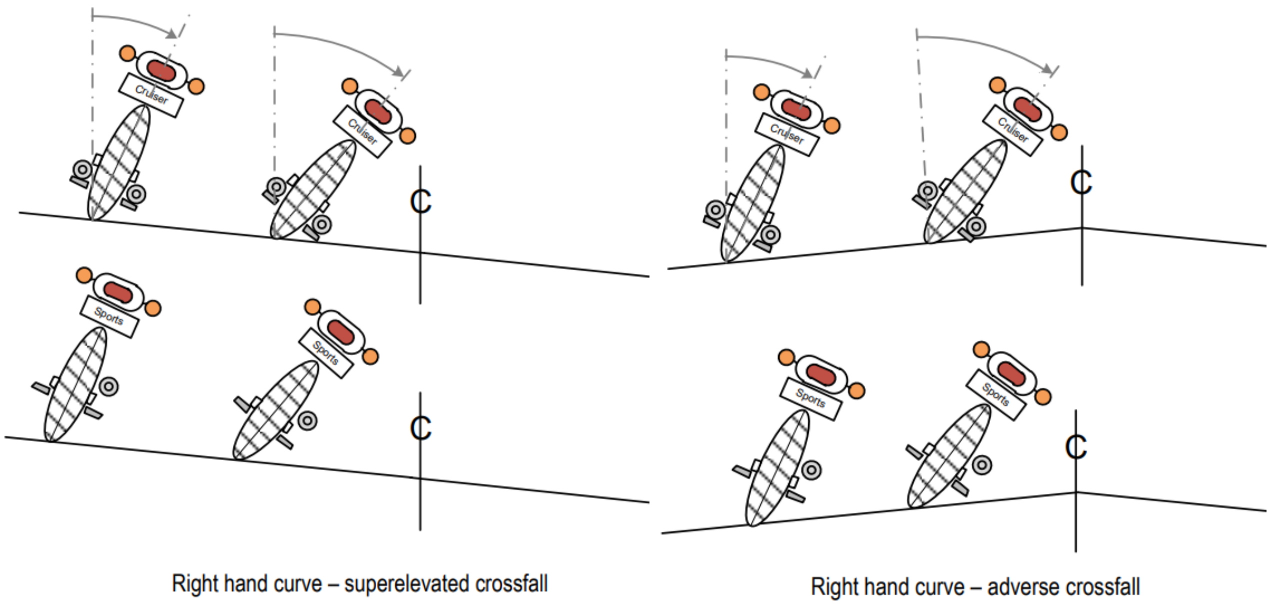
Roundabout crossfall and motorcycle stability

A motorcycle is required to lean on the circulating carriageway whilst accelerating or braking. This places a higher demand for grip which can sometimes exceed the available grip. A 'small' (tight) radius for the roundabout places a high demand on surface friction when the motorcycle is turning and accelerating, whereas a large radius places demand on surface friction given that the motorcycle's speed will typically be greater.

Whilst turning, a leaning motorcycle places a higher reliance on a hazard free road surface with adequate and consistent surface texture, particularly where there is also an adverse crossfall. Figure 4.15 below illustrates the reduction in ground clearance and greater likelihood of the motorcycle contacting the ground when adverse crossfall is implemented.

Crossfall should be adequate such that ponding of water does not occur on the circulating carriageway of the roundabout. Surface water can present a high risk of destabilisation for motorcyclists as sufficient surface grip may not be available.

Figure 4.15: Motorcycle clearance on curves



Source: Austroads (2016a).

Roundabouts on sloping topography

For roundabouts in slower speed areas where the terrain is relatively flat, adverse crossfall is usually provided on the circulating roadway. For roundabouts on general sloping topography, there may be benefit in designing the roundabout as a tilted plane with adverse crossfall in the lower half of the roundabout, and positive superelevation in the upper part of the roundabout. A particular example of this is the use of roundabouts at motorway/freeway ramp terminals where the circulating carriageway can be placed on a plane to match the gradient of either the intersecting road or the ramp. This arrangement can also avoid the:

- creation of sharp sag vertical curves on some of the approaches that would result from the use of continuous adverse crossfall on the circulating roadway, which can limit the ability of drivers to perceive vehicles on previous approaches
- circulating carriageway being obscured from drivers approaching down the gradient because a circulating carriageway on adverse crossfall would be cut into the hill
- poor aesthetics that can otherwise be produced (that is, a 'leaning' roundabout).

On circulating carriageways with varying crossfall, the superelevation should stay within the range of ± 4%. Grades on the circulating roadway greater than 4% should be avoided. Where the general slope of the land is greater than 4%, it will be necessary to ‘bench’ the area for the roundabout, using a desirable maximum grade of 3% with an absolute maximum grade of 4%.

4.10.2 Approach Grade

Generally, it is desirable that the gradient on approaches to roundabouts be limited to 3 to 4% and should not exceed 6%. While the gradient may extend along part of the length of the entry curve it is essential that:

- On an uphill approach a flat area (say 2–3% maximum) is provided on the immediate approach to the roundabout to accommodate the length of one design vehicle. This flat area will assist heavy vehicles to start up and move into gaps, ensure that capacity is not unduly compromised, and also assist with respect to sight distance.
- On a downhill approach a sag curve will be required to match the higher gradient to a 3% positive superelevation on the roundabout (Section 4.10.1).

4.10.3 Drainage

Drainage is an important consideration in the design of all intersections including roundabouts. Many roundabouts have negative superelevation on the circulating roadway, which simplifies drainage and maintenance by avoiding the use of pits around the central island. However, there may be circumstances where a road authority prefers to provide positive superelevation on a circulating roadway and drainage will have to be provided in the central island.

Where positive superelevated circulating roadways are used, water will drain from the circulating carriageway to the central islands. Drainage at the edge of the central island can be achieved by the provision of:

- regular breaks in the kerbing of the central island in conjunction with gently sloping sides (e.g. 1 on 10) on the outside of the central island, open drains and gullies or culverts
- kerb inlets and underground stormwater drainage.

An adverse crossfall or positive superelevation as low as 2% has been found to be adequate for pavement drainage provided construction tolerances are tightly controlled. Designers are also referred to the Austroads *Guide to Road Design Part 5A: Drainage: Road Surface, Networks, Basins and Subsurface (AGRD Part 5A)* (Austroads 2023e).

4.11 Special Treatments

4.11.1 Wide Medians and Streets of Unequal Width

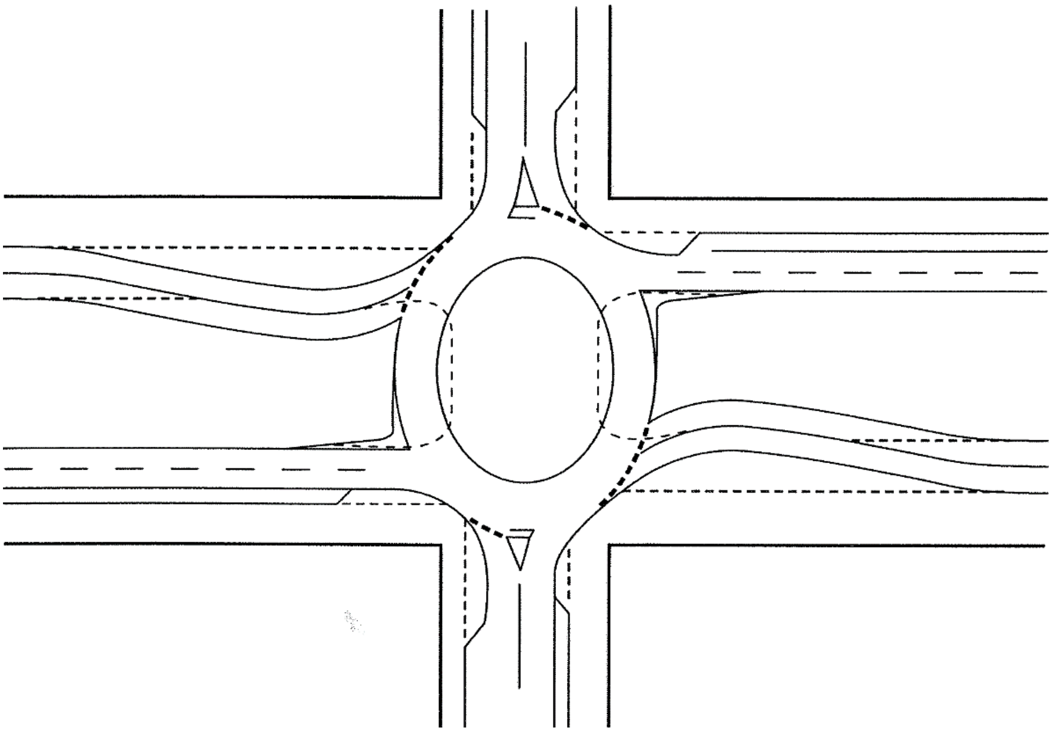
Particular problems in roundabout design occur at locations where one intersecting street is considerably wider than the other and/or where a wide median exists. This situation can occur on local, collector or arterial roads or, as is often the case, where the intersecting streets are not of the same functional classification. Very often a roundabout will not be the appropriate type of treatment in these cases. However, where the volume of traffic on the narrower street is greater than or equal to that on the wider street, and if there are heavy right-turn flows, a roundabout could be suitable.

Where a roundabout is proposed, special care should be taken to ensure that the design is in accordance with the guidelines given in this Guide. In particular, providing sufficient entry curvature for through traffic entering the roundabout is most important. Generally, a low-cost solution that does not require roadworks encroaching onto existing nature strips and/or the median will not be possible.

Figure 4.16 is an example of a roundabout designed for an undivided road crossing a divided road with a wide median. In these situations, the central island is not circular and as a result there will be different circulating speeds for different sections of the circulating carriageway. A circular roundabout at this type of location, although quite large, would provide a safer treatment and is therefore desirable, if space permits.

The oval island does not necessarily have to be aligned with the centreline of the intersecting roads. A designer may choose to orientate the oval to favour a predominant right-turning movement or to assist a substantial right-turning movement of heavy vehicles.

Figure 4.16: Roundabout on a road with a very wide median



Source: Department of Main Roads (2006) .

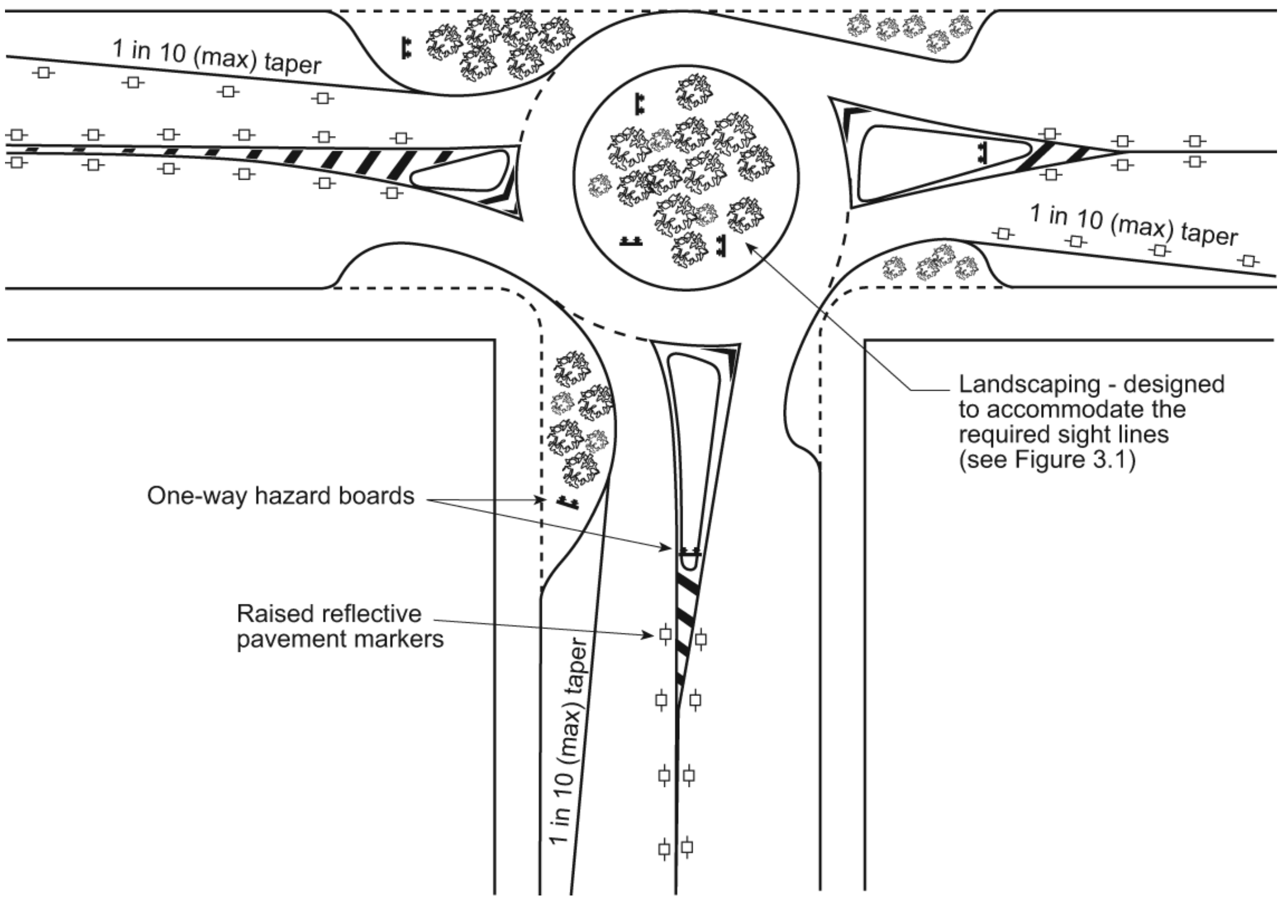
4.11.2 Wide Undivided Streets and T-intersections

Where a roundabout is to be constructed at an existing T-intersection, it is generally necessary to build out the kerb lines using ‘blisters’ to provide approach curvature or geometry that will slow entering traffic to a safe entry speed, particularly on the continuing road. This treatment is usually applied to local streets where the desired entry speed is quite low, e.g. 20 km/h. This practice may also be adopted at certain crossroad intersections where one cross street is wider than the other and/or where there is space for more than one lane of traffic on a particular approach.

Where kerb lines are to be built out on approaches to roundabouts, special care should be taken to ensure that adequate delineation is provided, particularly in instances where there are no parked vehicles on the approach. A suitable treatment using linemarking, raised retro-reflective pavement markers (RRPMs), and semi-mountable kerbs is shown in Figure 4.17.

This layout has been devised with the objective of providing a safe, well-delineated roundabout where entry speeds are controlled while limiting the amount of parking that has to be restricted. However, the layout must be able to accommodate the necessary design vehicle (e.g. service vehicle) and also provide for access by emergency vehicles (e.g. fire trucks).

Figure 4.17: Roundabout at T-intersections in an urban area



Source: Department of Main Roads (2006).

4.11.3 Mini-roundabouts

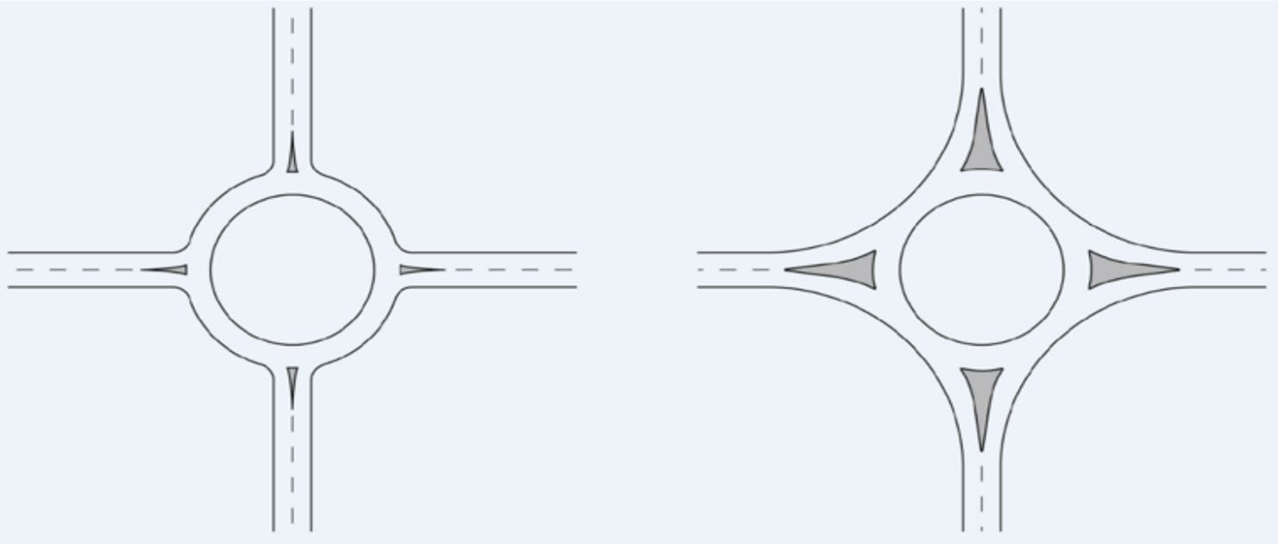
A mini-roundabout is a small roundabout with a solid painted circle or low traversable dome in the middle of the intersection. It can be used as an alternative where cost and/or space restrict the use of a traditional-sized roundabout, typically only on local roads. The benefits and issues relating to a traditional-sized roundabouts also apply to mini-roundabouts; however, there are considerations specific to mini-roundabouts. As the central and splitter islands may be painted only, mini-roundabouts tend to be less visible than traditional-sized roundabouts and adequate signage should be provided to ensure drivers are aware of the intersection. This is particularly important if the mini roundabout is located on a crest. For further design guidance on mini roundabouts refer to the Austroads *Guide to Road Design Part 7: New and Emerging Treatments* (AGRD Part 7) (Austroads 2021).

4.11.4 Radial Roundabouts

In Australia and New Zealand roundabouts are generally designed using the tangential approach rather than the radial approach that is commonly used throughout Europe. The geometric design features outlined throughout this Part are based on tangential roundabout design philosophy.

Figure 4.18 shows that the entries from the approach legs are aligned towards the centre of a radial roundabout, whereas there is significant deflection to the left for the approach to tangential roundabouts.

Figure 4.18: Radial roundabout design (left) and tangential roundabout design (right)



Source: VicRoads (2016).

While tangential roundabouts can improve safety for vehicles, they can be problematic for vulnerable road users such as pedestrians and cyclists. Due to the lack of entry deflection from the 90-degree approach to circulating radius, radial roundabouts can provide a slower environment, therefore increasing the level of safety for all road users. The entries and exits of radial roundabouts are also narrower than tangential roundabouts, which also aids in reducing the speed of vehicles. The downsides of a radial roundabout compared to a tangential roundabout may include reduced capacity due to the slower environment as well as potential challenges to access for larger vehicles due to the tighter geometry.

Radial roundabouts can be well suited to local roads with a more compact footprint leading to a potentially lower implementation cost.

5. Pedestrian and Cyclist Treatments

5.1 Introduction

Consideration should be given to the movement of pedestrians in the planning and design of roundabouts. Under National Transport Commission, (Road Transport Legislation, Australian Road Rules) Regulations 2012, vehicles leaving a roundabout are not obliged to give way to pedestrians. Roundabouts are therefore inappropriate where there is considerable pedestrian activity and, due to high traffic volumes, it would be difficult for pedestrians to cross either road unless pedestrian crossing facilities are provided, e.g. pedestrian crossings or pedestrian operated traffic signals across the legs of the intersection, refer also to Austroads *Guide to Traffic Management Part 6: Intersections, Interchanges and Crossings Management* (AGTM Part 6) (Austroads 2020d). In such cases, traffic signals are preferred to assist pedestrians to cross the road safely. At lower-trafficked intersections roundabouts may be appropriate and acceptable, but they should be designed to operate at speeds of 30 km/h or less and may incorporate pedestrian crossings (zebras) or raised pedestrian crossings to provide priority to pedestrians. Speeds can be minimised using vertical or horizontal deflections. If the latter approach is adopted a radial design is recommended. At busier roundabouts pedestrian signals may be required to provide safe and convenient movement for pedestrians.

A number of studies have shown that roundabouts increase the risk of crashes for cyclists and this needs to be taken into account when considering the adoption of a roundabout treatment at an intersection. Cyclists are involved as circulating vehicles in a high percentage of entering/circulating vehicle crashes and this is likely to relate to entry speeds and motor vehicle drivers' scanning behaviour on the approaches. The Safe System threshold for crashes involving pedestrians and cyclists is 30 km/h. Where entry or circulating speeds are above 30 km/h, consideration should be given to providing separate facilities for cyclists to negotiate a roundabout.

From a purely safety perspective, clear separation is the preferred option; however, it is acknowledged that the ability to construct infrastructure for grade separation of pedestrians and cyclists is limited due to cost, negative impacts on surrounding urban space and the potential requirement for pedestrians and cyclists to undertake significant and inconvenient diversions to cross the road. Alternative treatments such as bicycle or shared paths may be considered to negotiate roundabouts. Newer roundabout treatments, such as implementing raised platforms on approaches to both reduce speeds but also provide raised crossing points, have been trialled in low speed, urban environments with positive results. Initial information on this treatment can be found in the Austroads *Guide to Road Design Part 7: New and Emerging Treatments* (AGRD Part 7) (Austroads 2021). AGTM Part 6 provides guidance on road user considerations for roundabouts and on the appropriate and inappropriate use of roundabouts.

5.2 Pedestrians

5.2.1 Safety Analysis of Roundabouts for Pedestrians

While there may be a perception in some sections of the community that roundabouts are problematic for pedestrians, there is no evidence to suggest that roundabouts are less safe for pedestrians than other forms of intersection control. However, there is anecdotal evidence to suggest that children and elderly pedestrians feel less safe at roundabouts, particularly at exits. This is because, unlike traffic signals, roundabouts do not give priority to pedestrians over through traffic.

AGTM Part 6 cites a report by Tumber (1997) that suggests that roundabouts are at least as safe for pedestrians as other forms of intersection control because pedestrians are able to cross one direction of traffic at a time by staging their crossing on the splitter islands. It is also recognised that there are some pedestrians concerned with their safety as this method does not provide the pedestrian with priority in undertaking the crossing.

5.2.2 Designing Roundabouts for Pedestrians

Visually impaired people rely on vehicle noise to obtain cues whether it is safe to step onto the road. Roundabouts can therefore be challenging for them as traffic can be moving in different directions, which can be confusing. Their needs should therefore be considered, and it may be necessary to provide separate crossing points, away from the roundabout, to where vehicles only approach from two directions.

Pedestrian kerb ramps provided at roundabouts should be one or two car lengths in advance of the holding line, so that pedestrians crossing the road are not impeded by cars waiting on the approach. Features that could be expected to improve the level of service and safety for pedestrians include:

- appropriate entry and exit geometry to mitigate potential conflict speeds
- splitter islands that are large enough to comfortably accommodate pedestrians and enable drivers to anticipate their movement onto the road
- appropriate separation and/or protection for pedestrians waiting within splitter islands
- kerb ramps and crossings orientated to provide for pedestrians to travel in a straight line across the road by the shortest route and preferably located along pedestrian desire lines
- provision of pedestrian crossings on approaches (zebra or signalised)
- prohibition of parking on approaches to provide clear visibility
- crossings designed for persons who have a disability
- street lighting
- signs and vegetation located so as not to obscure pedestrians
- conformance to the Australian Commonwealth *Disability and Discrimination Act 1992* or the New Zealand *Human Rights Act 1993*, and also AS 1428.1 and NZS 4121
- pedestrians not given a false sense of security by painting pedestrian crosswalk lines, i.e. two parallel lines without traffic signals and not a formal pedestrian (zebra) crossing, across the entrances and exits of roundabouts as this suggests a priority that does not exist in the road rules.

Where a high pedestrian demand exists across one leg of an intersection with low to moderate pedestrian activity across other legs, it may be appropriate to provide a roundabout and signalised pedestrian crossing. A decision to provide the crossing should be supported by traffic analysis and consideration of potential safety issues. If this option is adopted the designer should:

- ensure that adequate separation is provided at the exit (e.g. two to four car lengths, 12 to 24 m preferred) – refer also to Section 4.4.3 and Figure 4.8 of AGTM Part 6
- determine whether the design should allow pedestrians to cross the road in one movement or be staged (i.e. pedestrians store in a median); in the latter case a barrier fence should be provided in the median and be orientated so that pedestrians are required to face on-coming traffic as they approach the pedestrian detector buttons.

Whether a roundabout provides a superior or degradation in safety and level of service for pedestrians will depend on the context. Where the alternative being considered is a traffic signal-controlled intersection, a roundabout with adequate splitter islands may provide improved safety and convenience by facilitating a staged crossing on streets with moderate demand and speed. Moreover, the elimination of uncontrolled right turns (a large proportion of motorist-pedestrian crashes at signalised intersections involve this movement) can further reduce the crash risk. Such benefits are compromised on higher-speed streets through the loss of definitive temporal separation that signals provide (particularly where right turns are also controlled).

On lower-traffic streets where the alternative treatment is a sign-controlled intersection the staged crossing will provide benefits across all arms, particularly across the major street, as average speeds on the major street will likely decrease. However, pedestrians will lose priority over all traffic movements at a roundabout and speeds on the minor street approach are likely to increase (compared to a give way or stop sign-controlled intersection). Wherever it is concluded a roundabout is the most appropriate treatment, and pedestrians are present, mitigations should be incorporated to facilitate these movements. This includes a geometry which encourages Safe System speeds and, where appropriate, zebra or raised zebra crossings (wombat) on the intersection arms. An example of such a design in an area with high pedestrian and motorist demand, but low speeds, is shown in Figure 5.1.

Figure 5.1: Local road roundabout with wombat crossings on all intersection arms along the pedestrian desire line (Cecil Street, South Melbourne)

Further information regarding the design of pedestrian facilities including crossings and kerb ramps is provided in Section 8 of AGRD Part 4.

5.3 Cyclists

5.3.1 Introduction

AGTM Part 6 describes the different types of cyclists that need to be catered for at roundabouts and the associated traffic management considerations.

The consideration of the treatments and/or traffic control measures needed to achieve an adequate level of safety for cyclists depend on:

- the daily vehicle traffic volume and the peak hour flows
- the proportion of cyclists in the total traffic flow
- the functional classification of the roads involved
- the overall traffic management strategies for the location.

5.3.2 Safety Analysis of Roundabouts for Cyclists

Designers should appreciate that, while roundabouts are safer than other types of intersections, roundabouts may not be as safe for cyclists as other road users (AGTM Part 6). The selection of a roundabout for the intersection will often depend on the proportion of cyclists and other non-motorised road users expected to use the roundabout, along with other factors such as the functional classification of the roads involved and the overall traffic management strategy to be adopted.

It is also important to understand that the risk to cyclists and pedestrians depends on the type of roundabout. While a single-lane, low-speed urban roundabout may be satisfactory for pedestrians and cyclists, multilane roundabouts, or poorly designed single-lane roundabouts with inadequate entry curvature that promotes high entry speeds, are less safe for cyclists and pedestrians.

Further information on the safety performance of cyclists at roundabouts can be found in AGTM Part 6.

5.3.3 Designing Roundabouts for Cyclists

Reducing the relative speed between entering and circulating vehicles, minimising the number of circulating lanes, and maximising the distance between approaches reduces the entering/circulating vehicle crash rates at roundabouts and should also minimise entering/circulating vehicle crashes involving cyclists. Therefore, the design concepts given in this Part to minimise entry speeds, should also minimise crashes involving cyclists.

The results of various studies indicate that a separated cycle path, located outside the circulating carriageway, is the safest design when there are high vehicle flows. On designated cycle routes that cater for commuter cyclists, consideration should be given to the provision of signalised intersections instead of roundabouts.

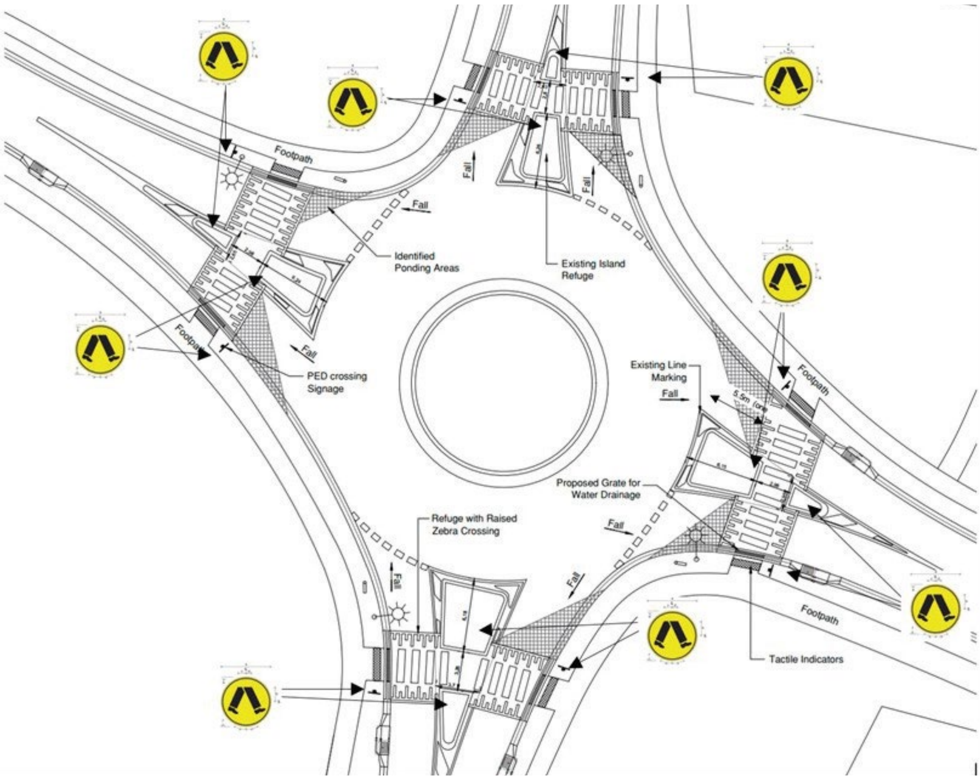
At small single-lane roundabouts on local streets, where the geometry encourages very low approach speeds (e.g. 20 km/h), cyclists should be able to safely share the road with general traffic. Specific guidance on geometric methods to achieve entry and circulating speeds of less than 30 km/h are still being developed and trialled. These are being assessed and will be included in future updates of this guide. The use of vertical displacement devices is an option to maintain reduced approach speeds, particularly on local roads in urban contexts.

The vertical displacement devices can also function as raised crossings for cyclists and pedestrians. If used for this purpose the crossing should be installed approximately one car length (6–8 m) back from the outer edge of the circulating carriageway. This treatment aims to moderate vehicle speeds to 30 km/h at crossings and provide priority to pedestrians and cyclists over vehicles entering/exiting roundabouts. On some larger roundabouts, it may be possible to locate the crossing further away from the circulating carriageway (up to 20 m) and taper the path gradually towards the crossing with minimal impact on desire lines. This can provide additional space for vehicle queuing or large vehicles. An example layout is shown in Figure 5.2.

If a crossing is not incorporated into the vertical displacement device then, from a cyclist perspective, road cushions or flat-top platforms are preferred to road humps as they reduce discomfort when travelling over the device. Where road humps are used, a bicycle-only bypass at the road hump can facilitate smoother bicycle travel (Figure 5.2). This bypass type of treatment provides a short separation from the traffic in the through-lane for the cyclist and requires the cyclist to merge into the through lane prior to the roundabout. Refer to AGRD Part 7 for further guidance on using raised platforms on approach to roundabouts to reduce approach speeds as well as the Austroads *Guide to Traffic Management Part 8: Local Street Management* (AGTM Part 8) (Austroads 2020b) on the different types of vertical deflection devices.

At larger single-lane or multilane roundabouts where speeds are higher, consideration should be given to separated treatments such as an off-road bicycle path around the roundabout with uncontrolled cyclist/pedestrian movement across each approach leg. There is some evidence to suggest that this is the safest design, at least where traffic flows are high.

Figure 5.2: Concept for retrofit of raised wombat crossing to tangential roundabout



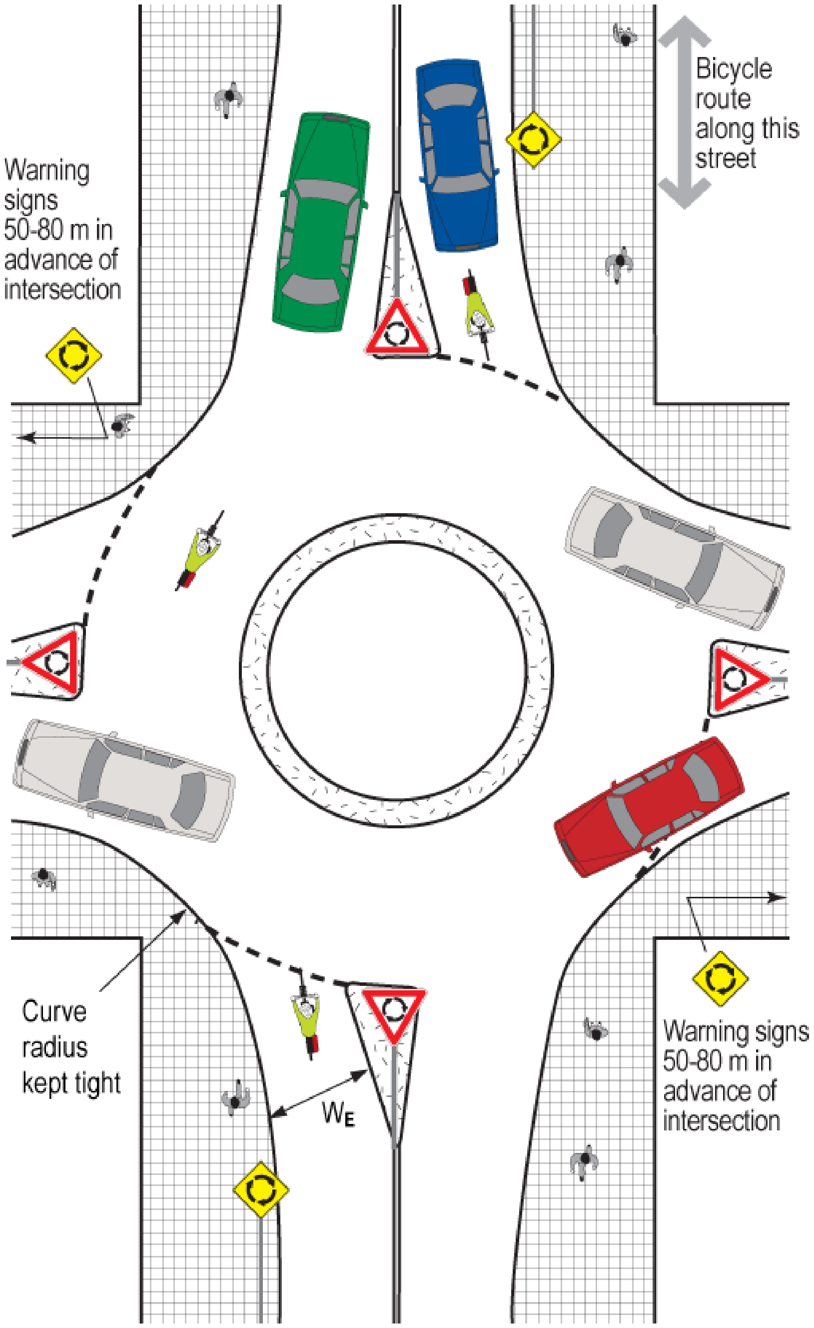
Source: Queensland Department of Transport and Main Roads (2021b).

5.3.4 Roads with Shared Traffic

Roads that have low traffic speeds (e.g. under the target speed of 30 km/h) and relatively low volumes (< 3000 vpd) generally enable cyclists to safely share the road with other traffic.

Figure 5.3 shows an example of a low-volume single-lane roundabout that is based on cyclists occupying the approach lane. The approach lane width should not exceed 3 m as wider lanes may encourage risky overtaking behaviour by motorists.

Figure 5.3: Bicycle route through single-lane roundabout – no bicycle facility



Note: The width of the entry W_E should cater for the design vehicle, e.g. service vehicle or fire truck. However, it is preferable that W_E be less than 3.0 m so that drivers do not attempt to enter the roundabout alongside cyclists and 'squeeze' them into the kerb.

Source: Adapted from Roads and Traffic Authority (2005).

To achieve a roundabout target entry speed of 30 km/h, it necessary to create an entry path radius of 20 m or smaller. An example of how this could be achieved at an existing local road roundabout is shown in Figure 5.4.

Figure 5.4: Example of entry alignment and central island on a local road to achieve the target speed

Source: Modified nearmap© (2015), 'VIC', map data, nearmap©, Sydney, NSW.

5.3.5 Multilane Roundabouts

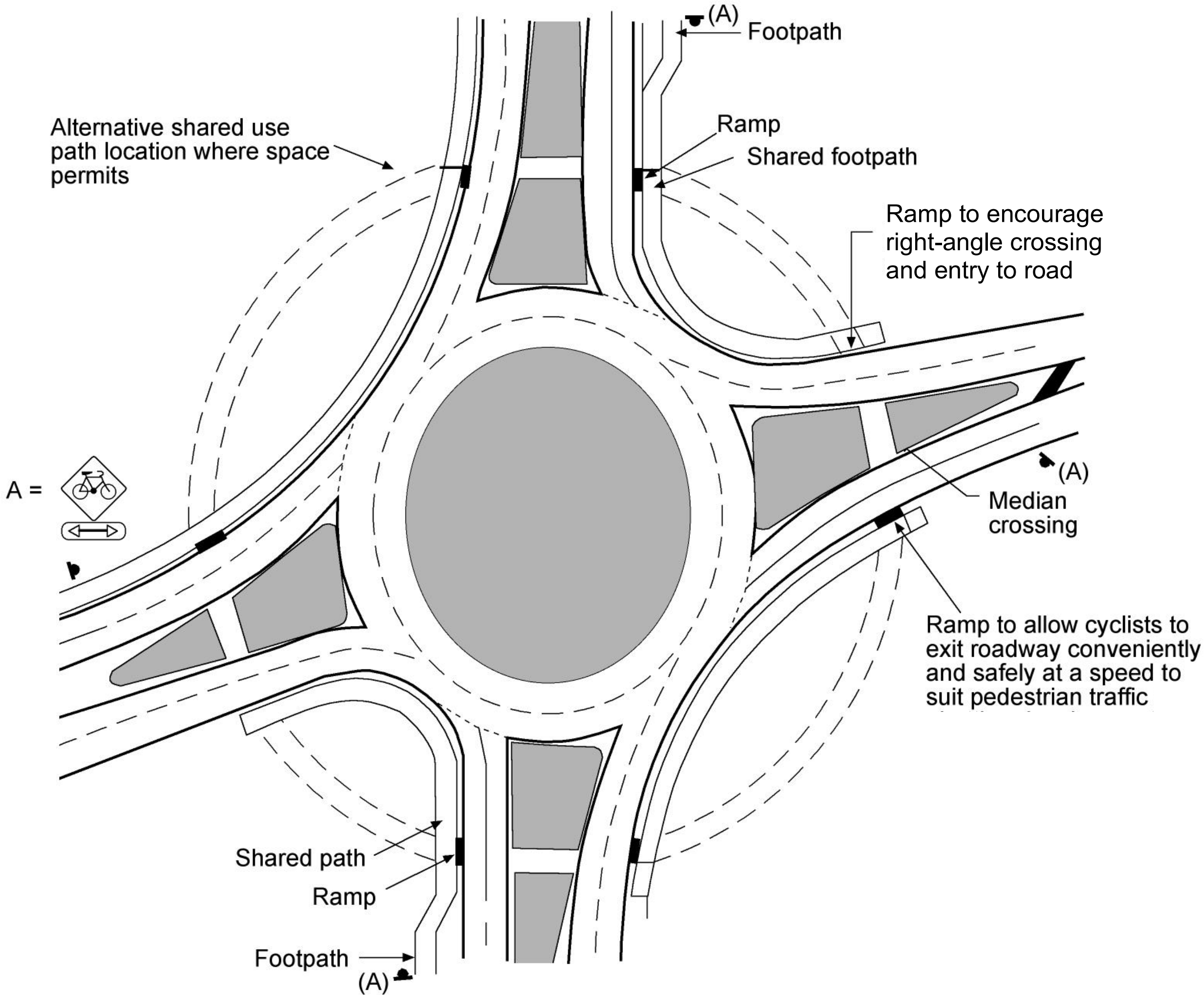
Multilane roundabouts usually carry high traffic volumes and have higher entry speeds than local street roundabouts and therefore create safety problems for cyclists. Experienced cyclists may feel reasonably comfortable in selecting a gap and either turning left or travelling straight through a multilane roundabout; however, they will generally find the right-turning manoeuvre challenging. Some cyclists will therefore bypass the right turn by using local streets, shared paths at the roundabout (where provided), or by undertaking a hook turn at the exit.

If vehicle speeds on the approach and circulating lanes cannot be reduced to the target speed of 30 km/h, then separated facilities are to be provided, e.g. grade-separated crossing or off-road paths. It should be noted that achieving the target speed is unlikely when vehicles are able to track across the lanes, effectively increasing the travel path curve radius.

5.3.6 Bicycle Paths and Shared Paths at Roundabouts

Bicycle paths or shared paths provided adjacent to roundabouts have been found to provide a safer passage for inexperienced cyclists and pedestrians, refer to AGTM Part 6. An example of a treatment where there is a relatively small volume of pedestrians and cyclists is shown in Figure 5.5.

Figure 5.5: Example of a path at roundabout where cyclist and pedestrian volumes are low to moderate

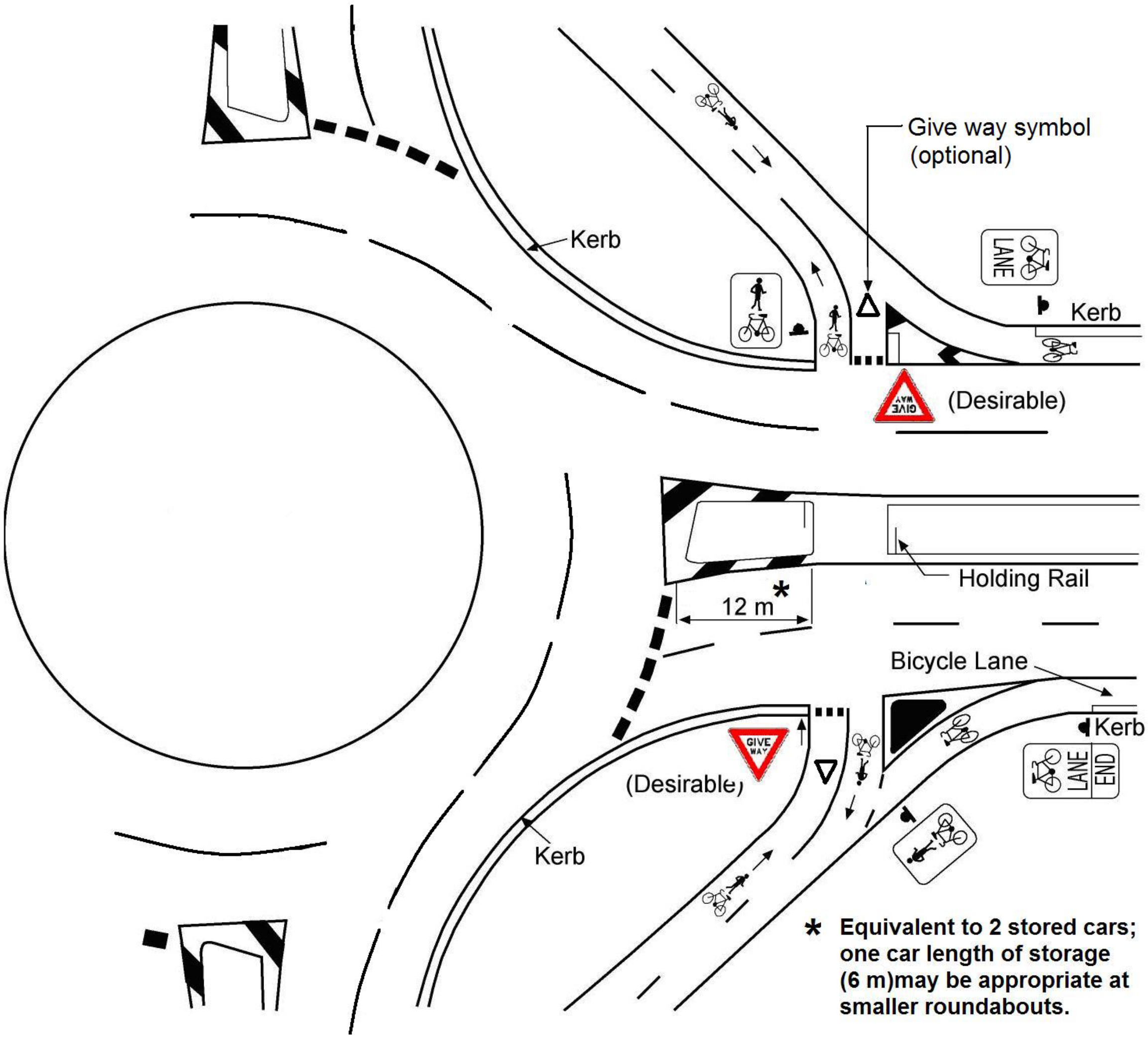


Source: Department of Main Roads (2006).

Where a shared path is provided at a roundabout and bicycle lanes exist on the approach, the crossing treatment shown in Figure 5.6 may be used. This treatment provides a crossing at road level, as well as convenient connections between the bicycle lanes and the paths to encourage cyclists to use the shared path to negotiate the roundabout. It should be noted that the treatment in Figure 5.6 requires cyclists using the shared path crossings to give way to approaching traffic.

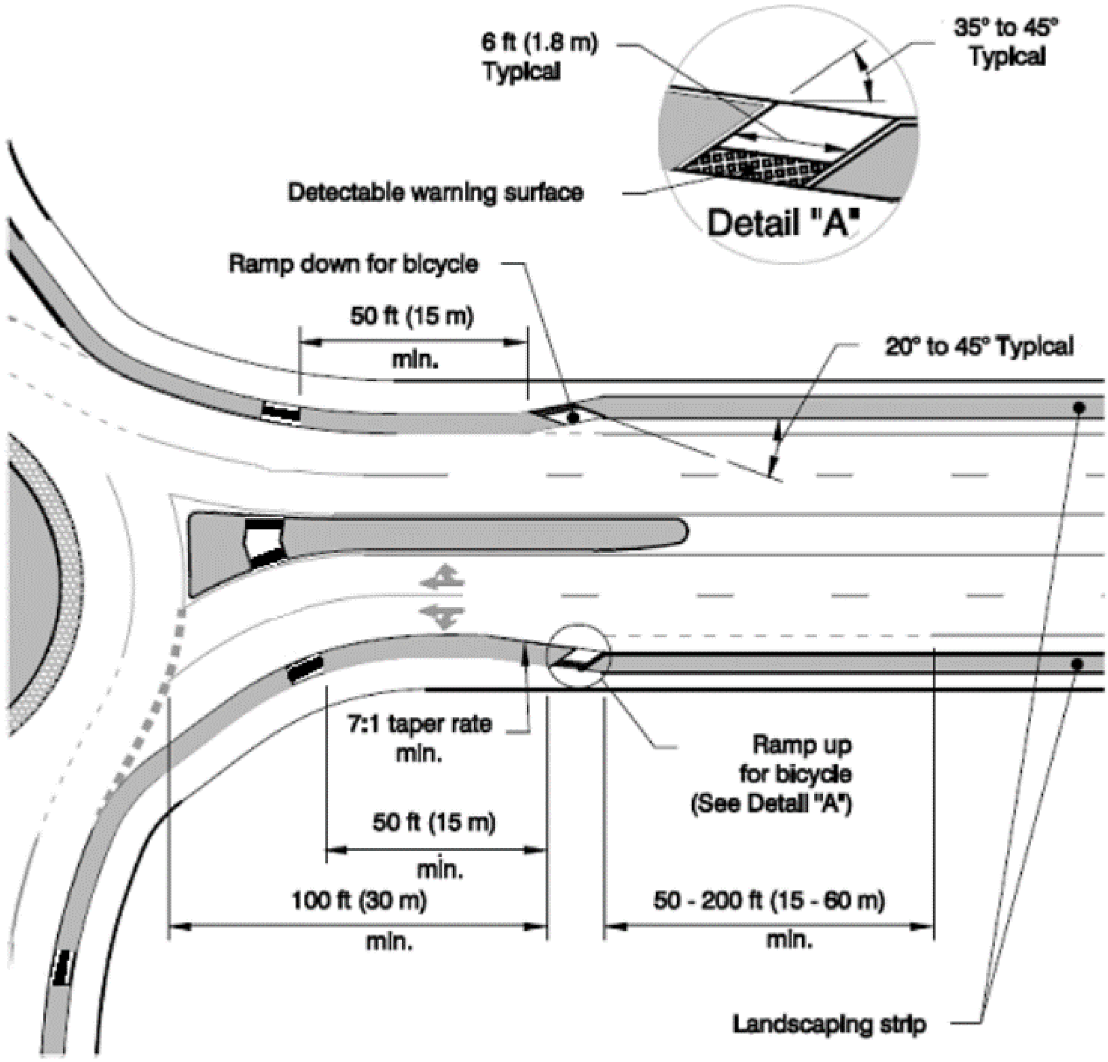
Kerb ramps can be used to ensure a smooth transition between an on-road bicycle lane and an off-road path (and vice versa). The kerb ramps in this application may be longer and wider than traditional footpath kerb ramps to ensure a sudden change in travel speed or direction is not required for the cyclist to negotiate the transition. Figure 5.7 shows the typical angle of the kerb ramp to the road is 20° to 45° for the down ramp and 35° to 45° for the up ramp. The off-road path connection should be located well in advance of the roundabout so that, if the cyclist decides to continue on-road, the manoeuvre into the through lane can be completed without disrupting the traffic flow close to the entry into the roundabout.

Figure 5.6: Crossing detail for a shared path adjacent to a multilane roundabout



Source: VicRoads (2005).

Figure 5.7: Kerb ramp angle between on-road bicycle lane and off-road path



Source: Queensland Department of Transport and Main Roads (2020).

5.3.7 Priority for Cyclists and Pedestrians at Roundabouts

Whilst roundabouts have been found to be effective in reducing the frequency and severity of motor vehicle crashes, the safety at roundabouts for cyclists and pedestrians remains a source of concern. Pedestrians do not have right of way and this can pose a safety issue at the exit of a roundabout, where a motorist is beginning to accelerate away from the intersection. Cyclists lack occupant protection, travel at slower speeds and are smaller in size when compared to occupants of motorised vehicles.

At multilane roundabouts, roundabouts with high vehicle volumes or roundabouts with high vehicle speeds (greater than 30 km/h) specific provision for cyclists is strongly recommended. The treatments specified in Section 5.3.6 provide bicycle paths or shared paths adjacent to the roundabout for safer passage; however, they still do not provide priority to pedestrians and cyclists crossing the roundabout. The use of raised crossings on the roundabout legs can change the priority and reduce inconvenience to pedestrians and cyclists negotiating the roundabout. It also helps to reduce vehicle speeds to the 30 km/h Safe System threshold for vulnerable road users.

Changing priority may lead to an increase in congestion and queuing within the circulating lane(s) and may also create issues where a vehicle does not sight a cyclist about to cross. The following questions should be asked when considering this type of treatment:

- Are there high volumes of pedestrian or cyclist movements at the roundabout?
- Does the bicycle path provide stimulation for the alertness of the cyclist?
- Are the crossing points clear and conspicuous?
- Are cyclists visible near the crossing point?

The use of raised crossing points on approach to roundabouts is still an emerging treatment. Refer to Section 5.3.3 or AGRD Part 7 for further guidance.

5.3.8 Other Considerations

Other situations where special consideration of cyclists is required to assist access and safety include the provision of a path to provide a bypass of three-legged roundabouts for cyclists travelling straight through the intersection.

To ensure that potential conflicts between cyclists and pedestrians are addressed, pedestrian movements must be considered where:

- it is proposed to construct separate perimeter paths around the outside of roundabouts
- shared-use paths exist around roundabouts.

6. Pavement Markings and Signing

6.1 Introduction

Roundabouts must be conspicuous if they are to function safely and effectively. High standards of delineation and signing must be provided. It is important that consistent arrangements of signs and other devices be provided to meet driver expectations. In Australia signs and markings should be generally consistent with AS 1742.2 – *Manual of Uniform Traffic Control Devices*, while in New Zealand they should comply with the *Manual of Traffic Signs and Markings* (MOTSAM) (NZ Transport Agency 2010a and NZ Transport Agency 2010b) and the *Guidelines for Marking Multi-lane Roundabouts* (NZ Transport Agency 2010c).

Practitioners in Australia and New Zealand should use the signs specified in the relevant standards so that drivers are provided with uniform signs and consistent messages throughout the respective nations. The temptation to invent new signs where a suitable standard sign exists, or to adopt different material and colours (e.g. in the case of hazard markers, the use of routed timber signs or municipal colours) should be resisted. Table 6.1 summarises some important aspects that practitioners should consider with respect to signs and markings at roundabouts.

The principles applied to roundabout signs and markings in New Zealand are similar, but the details differ.

Table 6.1: Some considerations in regard to signs and pavement markings

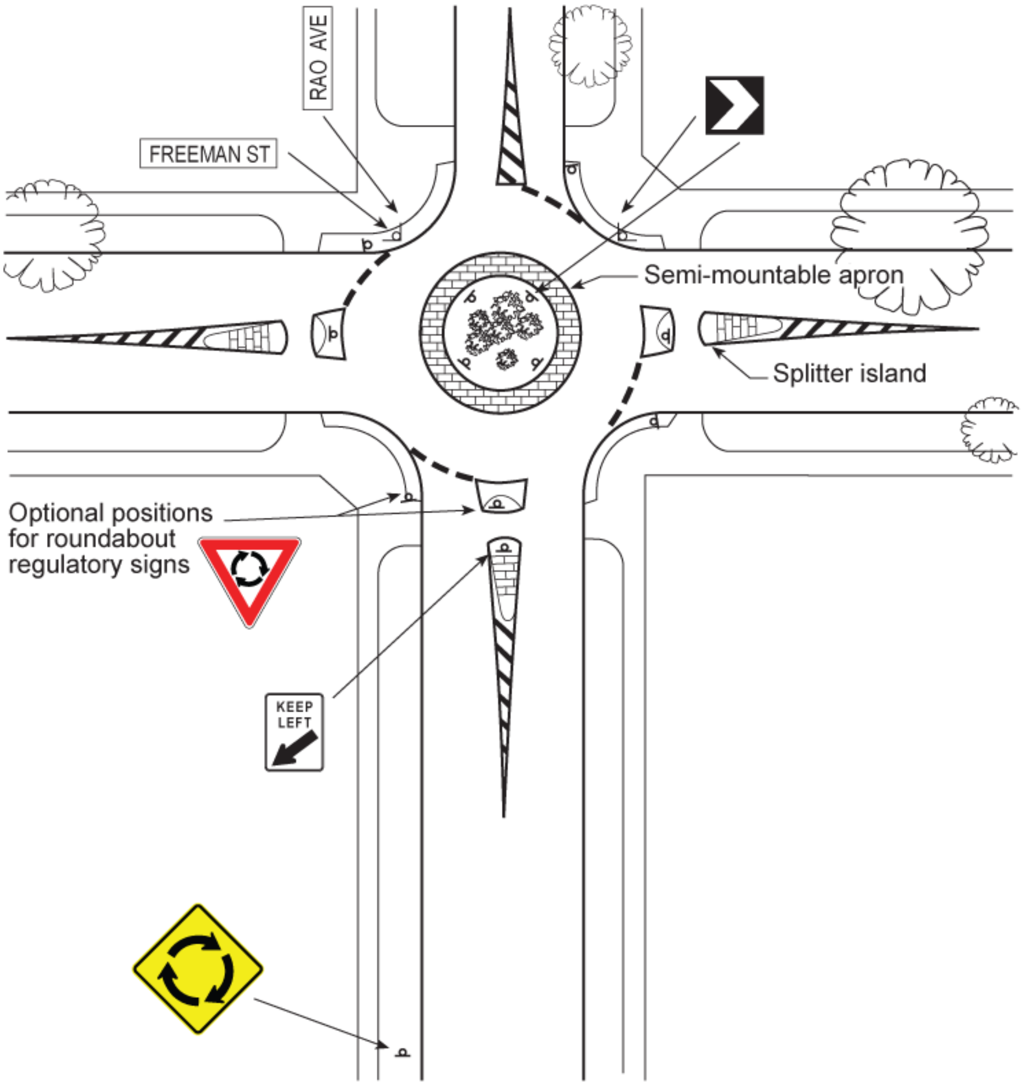
Traffic control device	Consideration
Pavement markings	• The holding line should be painted parallel to the circulating roadway, particularly at multilane approaches so that the drivers in the left lane can see past adjacent vehicles on their right • An edge line or continuity line should not be painted across the exit • In general, lane direction arrows are not necessary on the approaches to single-lane roundabouts • Lane direction arrows should be provided where there is more than one lane on an approach • Raised retro-reflective pavement markers may be used on lane lines to improve delineation at night • Pavement markings may be in paint. However, long-life materials (particularly in the circulating roadway of multilane roundabouts) should be considered to reduce the frequency of maintenance and ensure that good lane delineation is provided in critical areas • All pavement markings on approaches should desirably be visible to approaching drivers over the full length of approach sight distance • The skid resistance of pavement markings should be the same as the rest of the road. Pavement markings located in braking, accelerating, or turning locations will affect the stability of a motorcycle if they do not provide sufficient surface texture. Using large areas of pavement markings in traffic lanes is discouraged
Regulatory signs	• Place as near as practicable to the holding lines • Locate in the most prominent location (usually on the raised splitter island) • Provide on both sides of multilane entries • Provide an appropriate size for the speed environment. For arterial road roundabouts with high approach speeds or wide entry carriageways, size B or C signs should be used
Warning signs	• Generally necessary where the presence of a roundabout may be unexpected • May be used where a diagrammatic advance direction sign is not provided • Should be considered where approach speeds are high or approach sight distance is restricted
Hazard markers	• Place on central island opposite splitter island • Desirable on large splitter islands in high-speed areas to emphasise the curved approach

Traffic control device	Consideration
Advance direction signs	• Should be provided on all approaches to roundabouts in rural areas and, where practicable, on all major urban arterial roads • Large diagrammatic signs are preferred on high speed rural and urban arterial roads
Intersection direction signs	• To be placed on the left side of the circulating roadway at each exit • May be placed on the splitter island at an exit, provided that sight distance is not restricted for entering traffic • Mount at a height that does not impede either car or truck drivers' lines of sight

6.2 Single-lane Local Street Roundabout

Figure 6.1 represents the minimum arrangement of signs and markings that should be provided at a local street roundabout. Reference should be made to AS 1742.2 for further guidance. The regulatory signs and holding lines are essential. The advance warning sign is only necessary where there is poor visibility on an approach. The keep left signs often sustain damage in local streets because of the tight geometry for turning movements and their use is optional, except in situations where it is unclear whether traffic should pass to the left of the splitter island.

Figure 6.1: An example of signs and markings at a local street roundabout

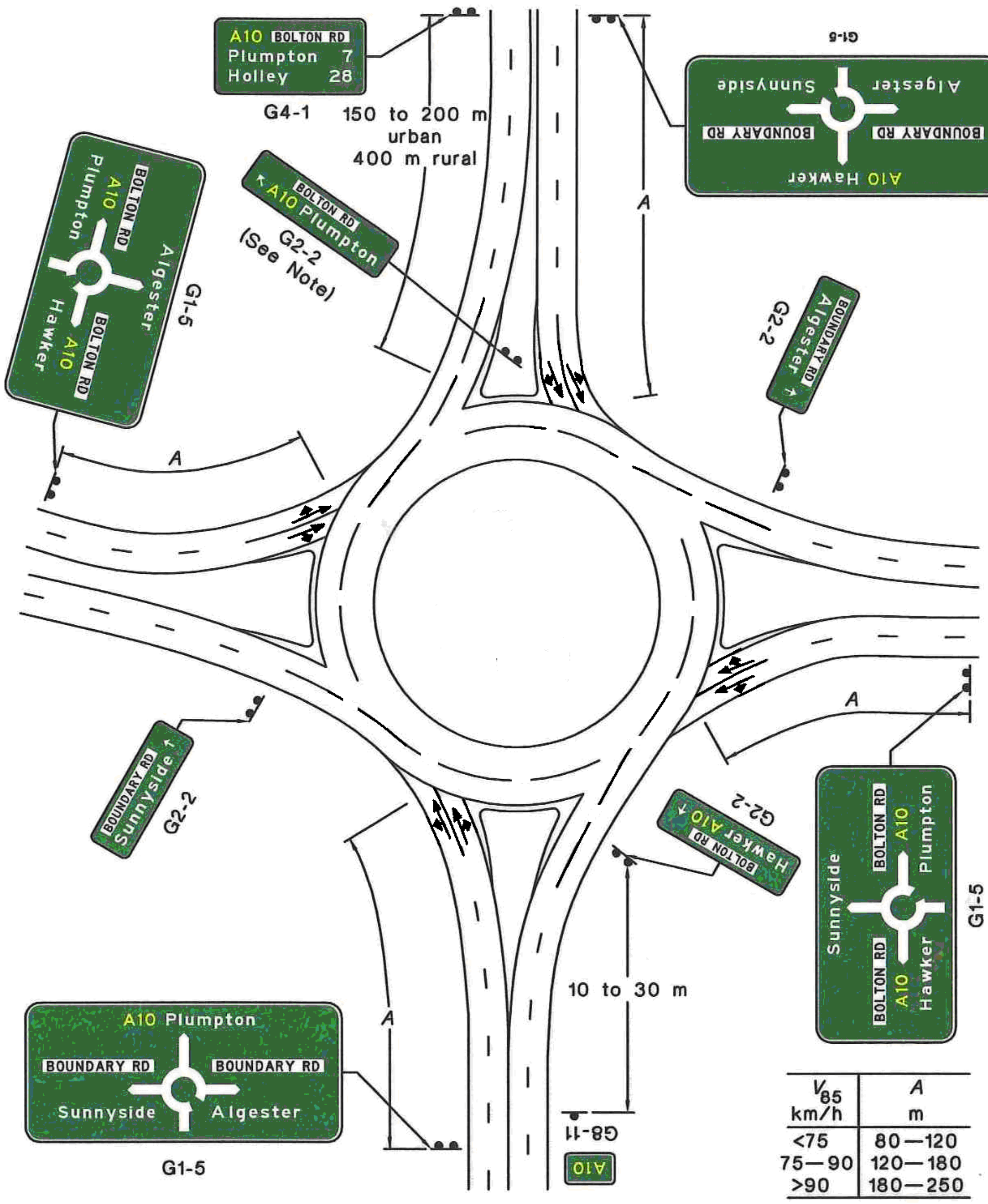


Source: Based on AS 1742.2. Signs shown for one approach only; provide on all approaches.

6.3 Multilane Arterial Road Roundabout

Figure 6.2 shows an example of signs and markings at a multilane roundabout. The roundabout regulatory signs, holding lines, pavement arrows on approaches, and exit lines are critical to the successful and safe operation of a multilane roundabout. Reference should be made to AS 1742.2 in Australia, and in New Zealand to MOTSAM (NZ Transport Agency 2010b) and the *Guidelines for Marking Multi-lane Roundabouts* (NZ Transport Agency 2010c).

Figure 6.2: An example of signs and markings at a multilane arterial road roundabout



NOTE: The intersection direction sign at each exit may be located on the island if it can be seen better by circulating traffic, and provided sight distance is not obscured. Otherwise it is placed on the left side of the exit as shown for other legs, ensuring that the arrow points clearly to the exit path rather than the continuing path around the roundabout.

A G2-2 sign with right hand horizontal arrow may be placed on the island if it is desired to confirm the direction to the next exiting leg.

Source: Based on AS 1742.15.

In special circumstances, a spiral marking treatment at multilane roundabouts may be required, e.g. to provide two-lane capacity from an entry leg to an exit beyond the second exit leg. Spiral linemarking may lead to increased driver workload and confusion and signage currently does not exist to adequately show the correct lane usage through the roundabout for particular movements. For this reason, it is desirable that spiral linemarking not be used for the design of roundabouts in greenfield sites. Instead, spiral linemarking should generally be considered only as a solution to minimising operational problems on existing roundabouts where no other solution is feasible. Refer to Appendix D for further information on roundabout linemarking.

7. Landscaping and Street Furniture

7.1 Introduction

Guidelines relating to landscaping within road reservations are provided in the Austroads *Guide to Road Design Part 6B: Roadside Environment* (AGRD Part 6B) (Austroads 2015c). Roundabouts can offer advantages over other forms of channelisation with respect to landscaping. However, the most important aspect is that roundabouts, including the landscaping and street furniture, are designed and installed to ensure a safe and forgiving roadside. Specifically, landscape design should not:

- create a danger to road users, particularly when vehicles leave the road
- impede the sight distance available to drivers approaching the roundabout or their ability to recognise the type of treatment
- obscure the view to potentially conflicting vehicles for a driver at the holding line of a roundabout.

Alternatively, carefully planned landscaping can enhance safety and amenity of the site by making the intersection a focal point and creating the perception of a low-speed environment. It is the responsibility of the road authority to achieve an appropriate balance between road safety and local amenity at any particular site.

Landscaping and the fixed objects that may be associated with it should be selected, designed, and located so that they do not have an adverse effect on an impacting vehicle. Adherence to this principle requires that:

- rocks, stone walls, power supply poles, or other fixed objects should not be placed in areas where vehicles are likely to run off the road
- signs and lighting poles should be frangible
- kerbs should be of a light colour (e.g. not bluestone), smooth and of a semi-mountable type
- steep ditches or culvert end walls should not be provided within the central island or adjacent to the roundabout
- trees and bushes with substantial trunks, should generally not be located in areas vulnerable to vehicle run-offs.

It is noted that some roundabouts are designed for a checking vehicle to drive over a fully mountable annulus (encroachment area) around the central island (Section 4.6.3) and that this area contributes to the clearance required to objects that may be placed in the central island.

It is also important to ensure that excessive stormwater run-off does not occur from the central island onto the circulating pavement. If this occurs, debris (e.g. mulch) may be carried onto the pavement and vehicle braking may be compromised.

7.2 Arterial Road Roundabouts

In addition to the above requirements, the grading and landscaping on arterial road roundabouts must be designed to ensure the achievement of sight distance requirements as set out in Section 3, and to avoid obstructing the visibility of signs. Otherwise, trees and other high landscaping features may be positioned in the inner area of the central island, provided it is large enough to ensure that sight lines are not impeded and clear zone requirements are met.

In addition, the landscaping of the central island should:

- clearly indicate to drivers that they cannot pass straight through the intersection; this is usually achieved by continuous kerbing and enhanced by mounding of the topsoil, appropriate planting and hazard markers, etc.
- ideally discourage the passage of pedestrians across to it (seats or similar attractions should not be provided in the central island)
- prevent parking or other vehicular access (except for maintenance purposes), unless the island is intended to be mounted by large design vehicles.

Generally, unless splitter islands are very large as in the case with wide medians, they should not be used to accommodate anything (e.g. trees, planter boxes, rigid lighting or power poles) that would adversely affect roadside safety or sight lines for vehicles approaching or entering roundabouts. As the splitter islands are located within critical sight triangles, care should be taken with landscaping to avoid obstructing sight distance.

Local authorities often provide landscaping within the central islands of roundabouts in order to enhance visual amenity. The relevant authority should ensure that roundabout central islands are not used to accommodate anything that would adversely affect roadside safety or sight lines for vehicles approaching or entering roundabouts.

On very large roundabouts planting, including trees, can be provided in the central island, whether it is raised or depressed. Figure 7.1 shows a very large roundabout where a large tree has been retained at an appropriate set-back from the central island kerb, with low planting in order to maintain sight triangles for entering and circulating traffic.

Figure 7.1: Example of a landscape treatment in the central island of a large roundabout

Note: Large tree and artwork in centre set well back from kerb. Grass and low-height ground cover used to maintain sight triangles.

On arterial road roundabouts that have smaller central islands (nominally less than 20–25 m in diameter) it is not usually possible to provide substantial planting and comply with sight distance and clear zone requirements. In these cases, low ground cover can be planted and the island raised at its centre by no more than 200 mm to facilitate drainage.

Landscaping within the central island will need to be kept outside the sight triangles as outlined in Section 3, unless low-growth vegetation is provided. The maximum mature height of this vegetation must be below the sight lines. The current and likely future maintenance regime must also be considered. Vegetation within the central island should preferably contrast with vegetation on the outside of the roundabout to help increase driver recognition of the central island. Large trees (i.e. > 100 mm diameter when mature) should not be planted in central islands of smaller arterial road roundabouts.

7.3 Local Street Roundabouts

Roundabouts on local roads have much slower approach and negotiation speeds and, if the central island is sufficiently large, these conditions can present an opportunity for landscaping. As speeds are lower, achieving appropriate sight distances should not be difficult and roadside hazard concerns will also be less critical. However, pedestrians are very likely to be present at these roundabouts – including children – and any landscaping or street furniture should not obstruct sightlines.

There is a need for roundabouts in local streets to be landscaped to complement the surrounding streetscape or to improve the appearance of a location. Local streets often appear as relatively open, wide and straight roads which do not reflect the desired speed environment (often 50 km/h or less). The provision of roundabouts and judicious planting not only improves the amenity of local streets but interrupts the visual continuity of the street and provides a perception of a lower speed environment.

For this reason, landscaping at roundabouts in local streets should provide a balance between road safety (in terms of sight distance and roadside safety) and amenity. It is suggested that a reasonable balance at a local street roundabout where the island is sufficiently large would be the provision of:

- a medium-sized tree (150 to 200 mm diameter) located centrally in the island with a minimum of 2.5 m clearance from the mature tree to the line of kerb
- associated low ground cover to a maximum height of approximately 200 mm
- a minimal number of low-mounted signs.

To avoid any sight distance issue due to the foliage of the tree, it is suggested that a reasonably mature tree should be planted so that the sight lines of car drivers and pedestrians are not impeded. Examples are provided in Figure 7.2 and Figure 7.3.

Figure 7.2: Example of a landscape treatment at a small local street roundabout

Figure 7.3: Example of a landscape treatment at a roundabout within a shopping precinct

7.4 Maintenance

The desire to establish vegetation needs to be considered in conjunction with the likely safety arrangements to maintain these treatments. This may affect the design of any vegetation, particularly in terms of proximity to the traffic lanes. The road designer and landscape designer need to jointly take these issues into account.

Maintenance of landscaping in the central island of arterial road roundabouts is difficult, and maintenance vehicles on the circulating roadway or the central island can create disruption and hazards to motorists. Any work therefore needs to be scheduled during off-peak traffic periods and preferably restricted to smaller machines and manual operations.

Watering systems for landscaping on central islands should be designed (e.g. a drip irrigation system) to prevent excess water or spray flowing onto the circulating roadway. Drivers on circulating roadways utilise a high degree of side friction to maintain stability and excess water on the road decreases the amount of side friction available and substantially increases the chance of single vehicle crashes.

Where landscaping is provided in central islands, particularly large islands, it is important to ensure that watering systems and drainage systems for roundabouts are designed to protect the road pavement by preventing seepage of water into the subgrade.

References

Allott and Lomax (1993) *Cyclists and roundabouts: a review of literature*, 2nd edn, Cyclist's Touring Club, Godalming, UK.

Arndt OK (2001) 'Geometric design of roundabouts for optimum safety: use of the software program 'ARNDT'', *ARRB Transport Research conference, 20th, 2001, Melbourne, Victoria, Australia,* ARRB Transport Research, Vermont South, Vic, 21 pp.

Arndt OK (2008) 'Speed control at roundabouts: use of maximum entry path radii'*, ARRB Transport Research conference, 23rd, 2008*, *Adelaide, South Australia,* ARRB Transport Research, Vermont South, Vic, 22 pp.

Arndt OK and Troutbeck RJ (1998) 'Relationship between roundabout geometry and accident rates', *International symposium on highway geometric design practices, 1995, Boston, Massachusetts,* Transportation Research Board, Washington, DC, USA, 16 pp.

Australian Transport Council (2011) *National road safety strategy 2011-2020*, ATC, Canberra, ACT.

Austroads (2010) *Road Safety Engineering Risk Assessment Part 9: Rural Intersection Crashes*, AP-T154-10, Austroads, Sydney, NSW. https://austroads.com.au/publications/road-design/ap-t154-10

Austroads (2014) *Methods for Reducing Speeds on Rural Roads: Compendium of Good Practice*, AP-R449-14, Austroads, Sydney, NSW. https://austroads.com.au/publications/road-safety/ap-r449-14

Austroads (2015a) *Guide to Road Safety Part 8: Treatment of Crash Locations*, AGRS08-15, Austroads, Sydney, NSW. https://austroads.com.au/publications/road-safety/agrs08-15

Austroads (2015b) *Improving the Performance of Safe System Infrastructure: Final Report*, AP-R498-15, Austroads, Sydney, NSW. https://austroads.com.au/publications/road-safety/ap-r498-15

Austroads (2015c) *Guide to Road Design Part 6B: Roadside Environment*, edn 2.1 2021, AGRD06B-15, Austroads, Sydney, NSW. https://austroads.com.au/publications/road-design/agrd06b

Austroads (2016a) *Infrastructure Improvements to Reduce Motorcycle Casualties*, AP-R515-16, Austroads, Sydney, NSW. https://austroads.com.au/publications/road-safety/ap-r515-16

Austroads (2016b) *Guide to Road Design Part 3: Geometric Design*, edn 3.4 2021, AGRD03-16, Austroads, Sydney, NSW. https://austroads.com.au/publications/road-design/agrd03

Austroads (2017) *Guide to Road Design Part 6A: Paths for Walking and Cycling*, edn 2.1 2021, AGRD06A-17, Austroads, Sydney, NSW. https://austroads.com.au/publications/road-design/agrd06a

Austroads (2020) *Guide to Traffic Management Part 4: Network Management Strategies*, AGTM04-20, Austroads, Sydney, NSW. https://austroads.com.au/publications/traffic-management/agtm04

Austroads (2020a) *Guide to Traffic Management Part 5: Link Management*, AGTM05-20, Austroads, Sydney, NSW. https://austroads.com.au/publications/traffic-management/agtm05

Austroads (2020b) *Guide to Traffic Management Part 8: Local Street Management,* AGTM08-20, Austroads, Sydney, NSW. https://austroads.com.au/publications/traffic-management/agtm08

Austroads (2020c) *Guide to Traffic Management Part 3: Transport Studies and Analysis Methods*, AGTM03-20, Austroads, Sydney, NSW. https://austroads.com.au/publications/traffic-management/agtm03

Austroads (2020d) *Guide to Traffic Management Part 6: Intersections, Interchanges and Crossings Management*, AGTM06-20, Austroads, Sydney, NSW. https://austroads.com.au/publications/traffic-management/agtm06

Austroads (2021) *Guide to Road Design Part 7: New and Emerging Treatments*, AGRD07-21, Austroads, Sydney, NSW. https://austroads.com.au/publications/road-design/agrd07

Austroads (2021a) *Guide to Road Design Part 1: Objectives of Road Design*, AGRD01-21, Austroads, Sydney, NSW. https://austroads.com.au/publications/road-design/agrd01

Austroads (2021b) *Guide to Road Safety Part 3: Safe Speed,* AGRS03-21, Austroads, Sydney, NSW. https://austroads.com.au/publications/road-safety/agrs03

Austroads (2022) *Guide to Road Design Part 6: Roadside Design, Safety and Barriers*, AGRD06-22, Austroads, Sydney, NSW. https://austroads.com.au/publications/road-design/agrd06

Austroads (2023a) *Austroads Design Vehicles and Turning Path Templates Guide*, AP-G34-23, Austroads, Sydney, NSW. https://austroads.com.au/publications/road-design/ap-g34

Austroads (2023b) *Guide to Road Design Part 4: Intersections and Crossings: General*, edn 2.2 2023, AGRD04-23, Austroads, Sydney, NSW. https://austroads.com.au/publications/road-design/agrd04

Austroads (2023c) *Guide to Road Design Part 4A: Unsignalised and Signalised Intersections*, edn 3.2 2023, AGRD04A-23, Austroads, Sydney, NSW. https://austroads.com.au/publications/road-design/agrd04a

Austroads (2023d) *Guide to Road Design Part 4C: Interchanges*, edn 2.1 2023, AGRD04C-23, Austroads, Sydney, NSW. https://austroads.com.au/publications/road-design/agrd04c

Austroads (2023e) *Guide to Road Design Part 5A: Drainage: Road Surface, Networks, Basins and Subsurface*, AGRD05A-23, Austroads, Sydney, NSW. https://austroads.com.au/publications/road-design/agrd05a

Balsiger O (1992) 'To plan for cycling is to encourage it' (in French)*, The bicycle: global perspectives*: *papers presented at the conference Velo Mondiale, pro bike, Velo City, Montreal, Quebec, Canada,* Velo Quebec, Canada.

Brude U and Larsson J (1996) *The safety of cyclists at roundabouts: a comparison between Swedish, Danish and Dutch results,* Swedish National Road and Transport Research Institute, VTI, Sweden.

Department of Main Roads (2006) *Road planning and design manual: chapter 14: roundabouts*, DMR, Brisbane, Qld.

McDonald M (2018) 'Achieving safer and more efficient urban roundabouts', *2018 Engineering technology forum*, Queensland Department of Transport and Main Roads, Brisbane, Qld.

NZ Transport Agency (2010a) *Manual of traffic signs and markings (MOTSAM): part 1: traffic signs*, NZTA, Wellington, New Zealand.

NZ Transport Agency (2010b) *Manual of traffic signs and markings (MOTSAM): part 2: markings*, NZTA, Wellington, New Zealand.

NZ Transport Agency (2010c) *Guidelines for marking multi-lane roundabouts*, NZTA, Wellington, New Zealand, viewed 20 January 2022, <http://www.nzta.govt.nz/resources/guidelines-marking-multi-roundabouts/docs/guidelines-multi-lane-roundabouts.pdf>.

Queensland Department of Transport and Main Roads (2020) *Providing for people walking and riding bikes at roundabouts*, TMR, Brisbane, Qld.

Queensland Department of Transport and Main Roads (2021a) *Road planning and design manual: volume 3: guide to road design*, 2nd edn, TMR, Brisbane, Qld.

Queensland Department of Transport and Main Roads (2021b) *Road planning and design manual: volume 3: Supplement to Austroads Guide to Road Design Part 4B: Roundabouts*, TMR, Brisbane, Qld.

Roads and Traffic Authority (2005) *NSW bicycle guidelines*, version 1.2, RTA, Sydney, NSW.

Robinson DL (1998) 'Accidents at roundabouts in New South Wales', *Road and Transport Research,* vol. 7, no. 1, pp. 3–12.

Tumber C (1997) 'Review of pedestrian safety at roundabouts', internal report, Road Safety Department, VicRoads, Kew, Vic.

Turner S, Wood G and Roozenburg A (2006) *Accident prediction models for roundabouts*, Beca Infrastructure Ltd, Auckland, New Zealand.

Van Minnen J (1996) *Safety of bicycles on roundabouts deserves special attention*, SWOV Institute for Road Safety Research, Leidschendam, Netherlands.

VicRoads (1999) *Designing local roads for ultra low floor buses*, information bulletin, VicRoads, Kew, Vic.

VicRoads (2005) *Providing for cyclists at roundabouts*, cycle notes no. 15, VicRoads, Kew, Vic.

VicRoads (2016) *Traffic engineering manual: volume 3: additional network standards & guidelines guidance on bicycle and pedestrian treatments at roundabouts*, VicRoads, Kew, Vic.

Australia and New Zealand Standards

AS/NZS 1158-2020 (set), *Lighting for roads and public spaces*.

Australian Standards

AS 1428.1-2009, *Design for access and mobility: part 1: general requirements for access: new building work*.

AS 1742.2-2009, *Manual of uniform traffic control devices: part 2: traffic control devices for general use.*

AS 1742.15:2019, *Manual of uniform traffic control devices: part 15: direction signs, information signs and route numbering.*

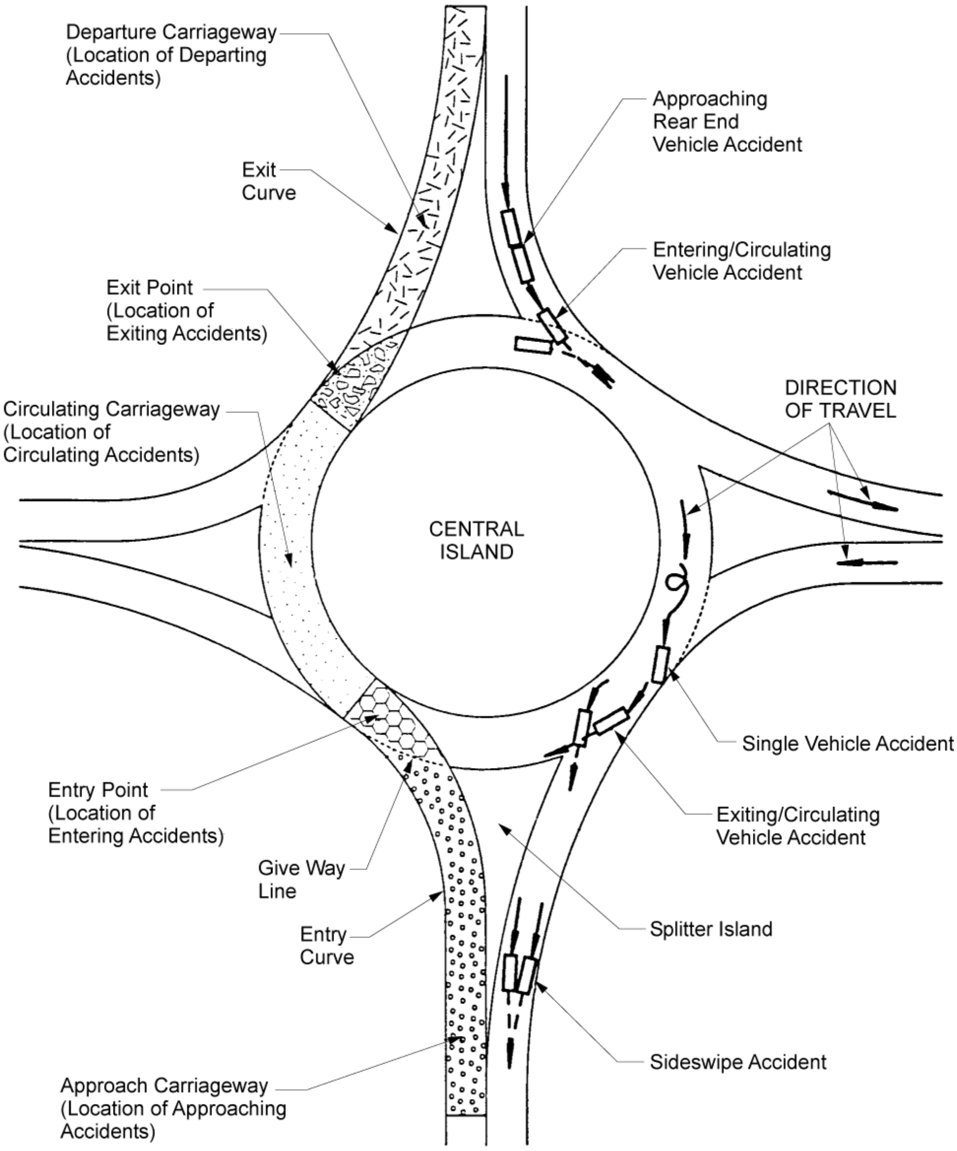
NZS 4121:2001*, Design for access and mobility: buildings and associated facilities.*

Appendix A Crash Types

A.1 Australia

Figure A 1 illustrates various geometric elements and crash categories used in the roundabout study by Arndt and Troutbeck (1998). Figure A 2 breaks down the total number of crashes into the various categories used in the study.

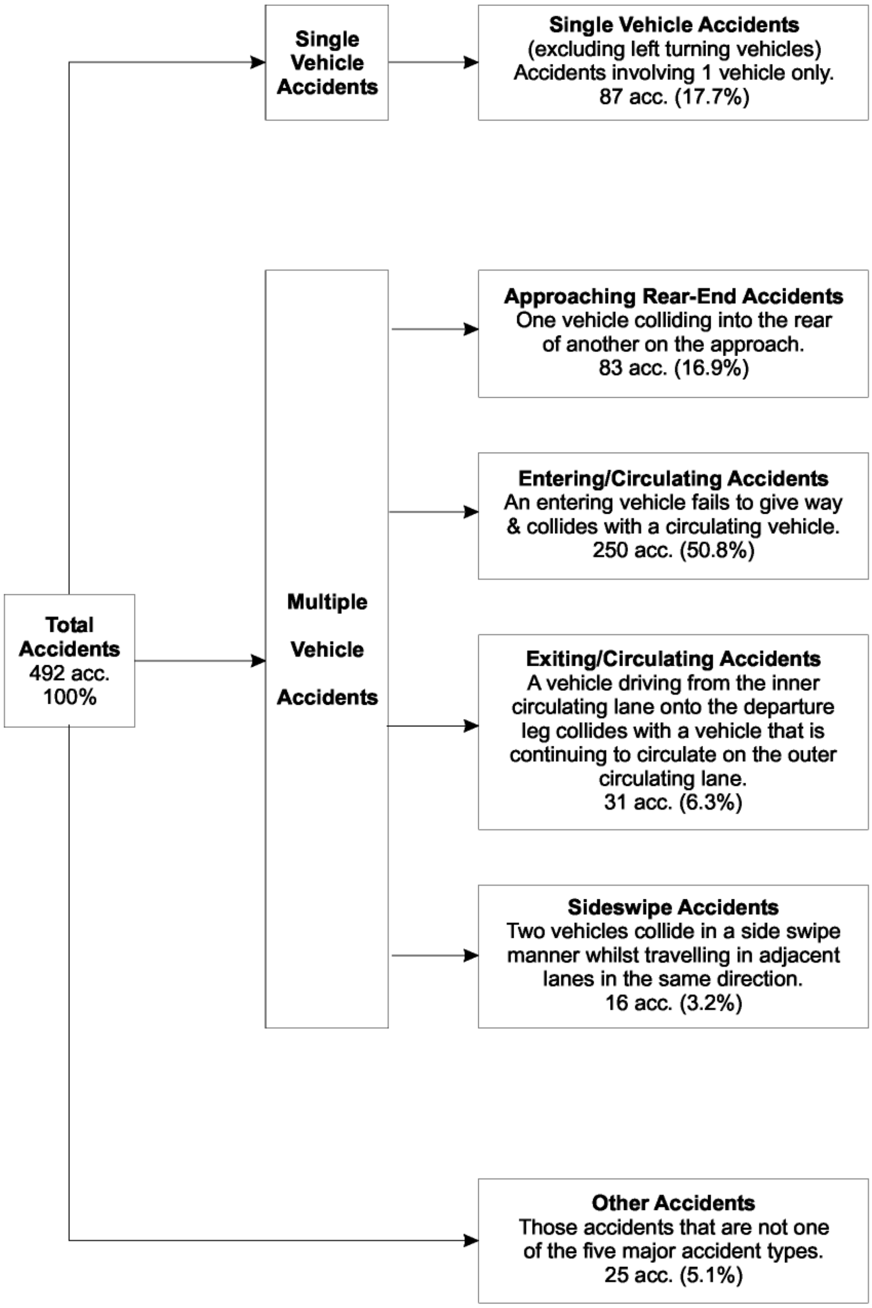
Figure A 1: Geometric elements of a typical roundabout and typical crash types



Note: Single vehicle and sideswipe crashes can occur on entry curves, circulating carriageway, and exit curves.

Source: Department of Main Roads (2006).

Figure A 2: Crash categories



Source: Department of Main Roads (2006).

A.2 New Zealand

Research has been undertaken to develop accident models for roundabouts in New Zealand (Turner, Wood & Roozenburg 2006). The paper focuses on the relationship between accidents, speed, traffic volume, and sight distance for various approaches and circulating movements at roundabouts. Given the different impact vehicle speed is expected to have on the 'active' modes (walking and cycling), separate models were developed for the major accident types for each mode. All accident types were grouped by road user involvement and proportion of accident type. The paper provides urban roundabout crash prediction models for accident type groups as follows:

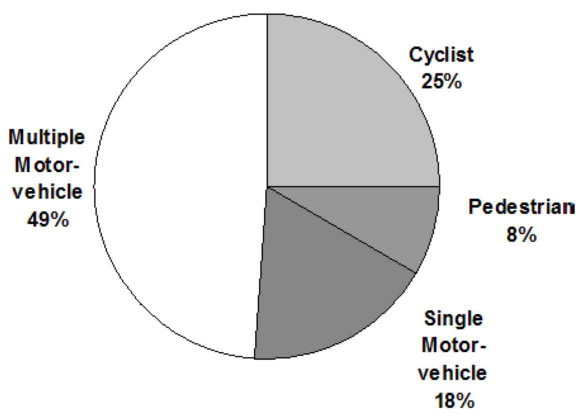
- entering vs circulating (motor vehicle only)
- rear end (motor vehicle only)
- loss of control (motor vehicle only)
- other (motor vehicle only)
- pedestrian
- entering vs circulating (cyclist circulating)
- other (cyclist).

The accident type groups to be modelled were determined from the analysis of national accident data for roundabouts extracted from the Ministry of Transport's Crash Analysis System (CAS) for the period 1 January 2001 to 31 December 2005.

Figure A 3 shows the proportion of reported injury accidents at roundabouts nationally involving single motor vehicles only, multiple motor vehicles only, cyclists, and pedestrians. This shows that 67% of accidents involve motor vehicles only and 25% involve a cyclist.

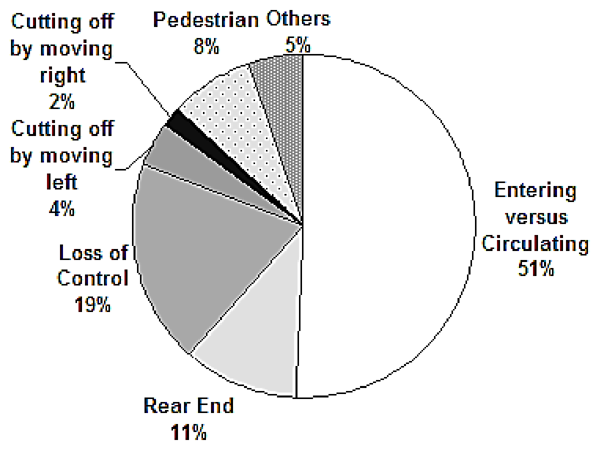
Figure A 4 shows the proportion of major injury accident types occurring nationally; this has not been categorised by vehicle type. However, the most common cycle accident type is entering versus circulating (82% of cycle accidents), 74% of which occur with the cyclist circulating and a motor vehicle entering.

Figure A 3: Road user involvement in injury accidents at urban roundabouts



Source: Turner, Wood and Roozenburg (2006).

Figure A 4: Injury accident types of reported crashes at urban roundabouts



Source: Turner, Wood and Roozenburg (2006).

Appendix B Roundabout Study and Program

Arndt and Troutbeck (1998) is a major Queensland study that linked the geometry of roundabouts to driver speeds and crash rates. The criteria were based on a vehicle path model and a speed prediction model. A recommendation of the study is to adopt the following limits for particular criteria at roundabouts in order to minimise crash rates:

- a maximum entry speed of 60 km/h to minimise rear-end crashes on the entry curve
- a maximum relative speed of 50 km/h between entering and circulating vehicles to minimise crashes between these vehicle streams
- a maximum decrease in speed between successive horizontal elements (e.g. entry curve and circulating carriageway), to minimise single vehicle crashes. Generally, this value is 20 km/h
- a difference in potential side friction of 0.7 (a measure of the degree that drivers will cut lanes on a multilane roundabout leading to higher sideswipe vehicle crashes). This criterion is for multilane roundabouts only and will minimise sideswipe vehicle crashes on the entry curve
- a maximum relative speed of 35 km/h between exiting and circulating vehicles to minimise crashes between these vehicle streams. This criterion is for multilane roundabouts only.

The above criteria were used to set the minimum central island radii of circular roundabouts, as given in Table 4.1 in this Guide. The maximum entry path radii in Table 4.2 in this Guide are also based on limiting the values of particular roundabout safety parameters.

Because of the amount of design effort required to manually calculate the values of all of these parameters, the computer program ARNDT was developed. Users of the program input geometric, traffic volume and speed environment data for a particular roundabout. The program outputs values of the criteria listed above and identifies any parameters exceeding the maximum limits.

A copy of this program can be downloaded from the internet at (www.mainroads.qld.gov.au). To locate the program, use the search function with the keyword 'ARNDT'. The program is freeware, but needs to be registered before use.

The findings of Arndt and Troutbeck (1998) and the use of the ARNDT program are discussed in Arndt (2001).

Appendix C Methods of Improving Roundabout Entries

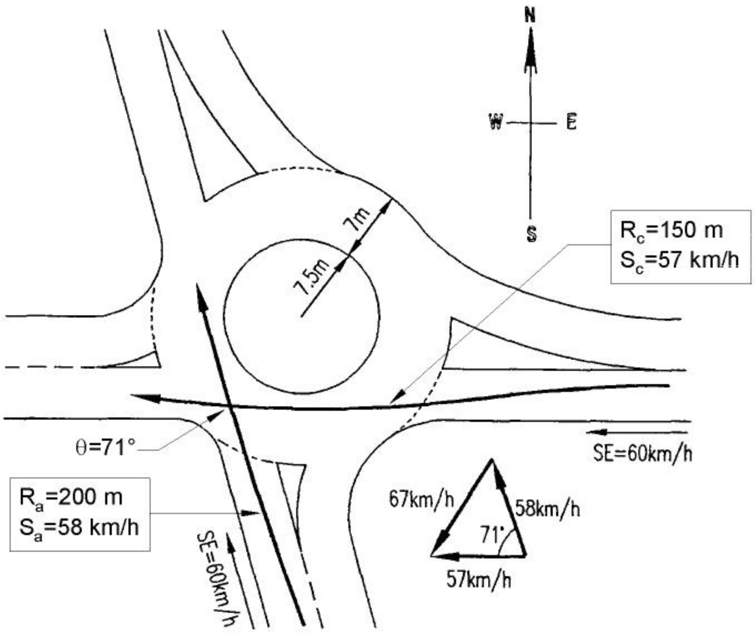
C.1 Introduction

Poor roundabout design is often a function of inadequate entry curvature. This appendix illustrates the effects of inadequate entry curvature and provides examples (Appendix C.2). A comparison of the relative speeds that would result at similar roundabouts if inadequate curvature and appropriate curvature were provided is shown in Figure C 1 and Figure C 2, respectively.

Figure C 1 shows a single-lane urban roundabout where the eastern and southern approach legs are in an area with a 60 km/h desired speed and both have little entry curvature. The relative speed of entering and circulating vehicles on the southern leg is 67 km/h. This high potential relative speed can produce high multiple vehicle crash rates between entering and circulating vehicles.

Figure C 2 shows the same roundabout with the central island relocated to obtain greater entry curvature. In addition, the width of the approach legs has been narrowed. The relative speed of entering and circulating vehicles on the southern leg is 37 km/h for this layout. This is a considerable reduction in relative speed of entering vehicles and will considerably lower the multiple vehicle crash rates between entering and circulating vehicles.

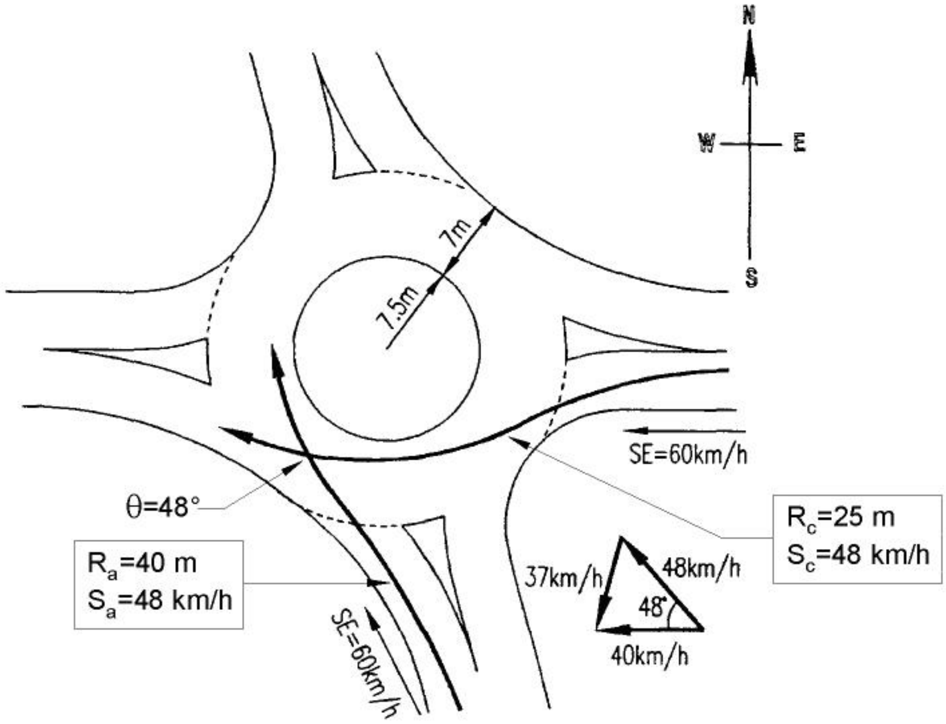
Figure C 1: Single-lane urban roundabout showing relative speed – adjacent approaches with minimal entry curvature



Notes:
R_C is the vehicle path radius for approach c.
S_C is the vehicle speed on R_C.
R_a is the vehicle path radius for approach a.
S_a is the vehicle speed on R_C.
SE is the approach road speed.

Source: Department of Main Roads (2006).

Figure C 2: Single-lane urban roundabout showing relative speed – adjacent approaches with substantial entry curvature



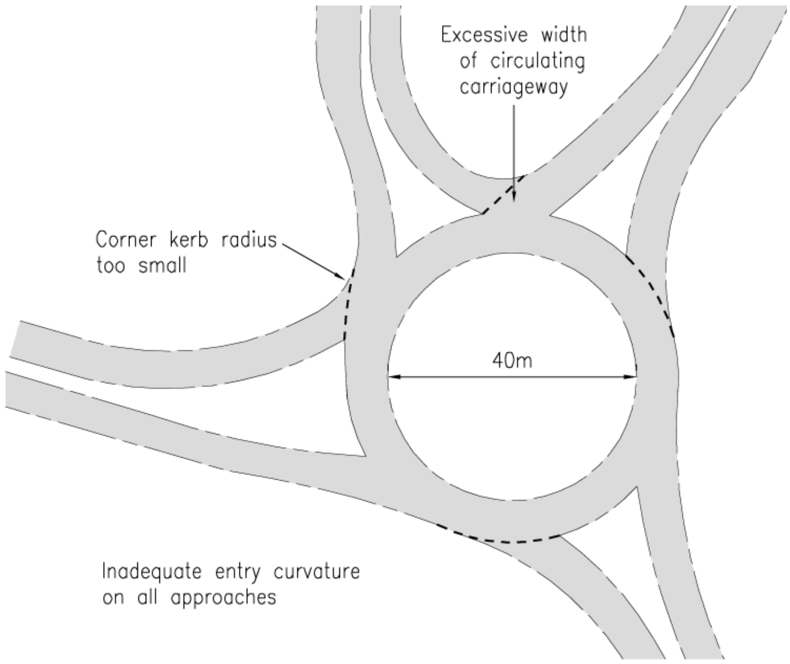
Notes:
R_C is the vehicle path radius for approach c.
S_C is the vehicle speed on R_C.
R_a is the vehicle path radius for approach a.
S_a is the vehicle speed on R_C.
SE is the approach road speed.

Source: Department of Main Roads (2006).

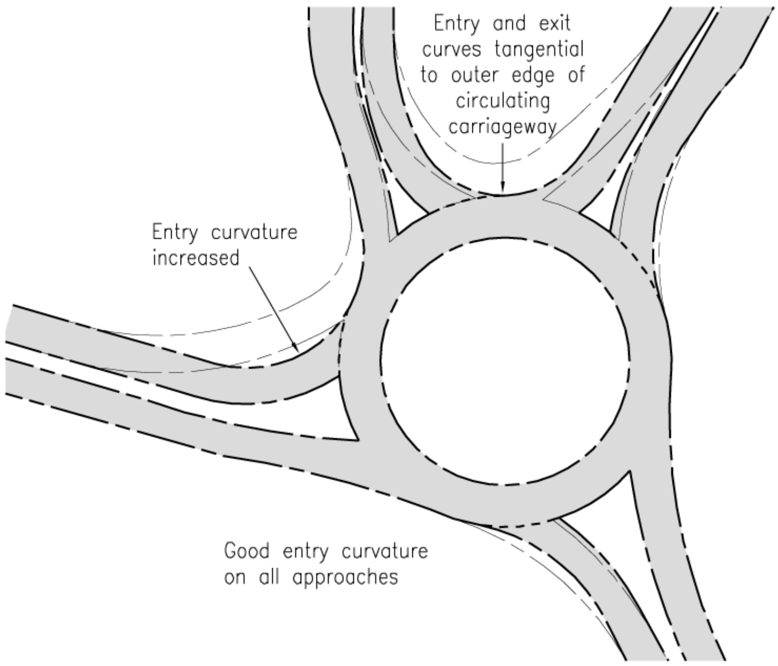
C.2 Examples of Improved Roundabout Entries

Figure C 3, Figure C 4 and Figure C 5 show examples of roundabouts with poor entries and recommended designs that provide acceptable geometry.

Figure C 3: Example 1 – design modifications to improve geometry



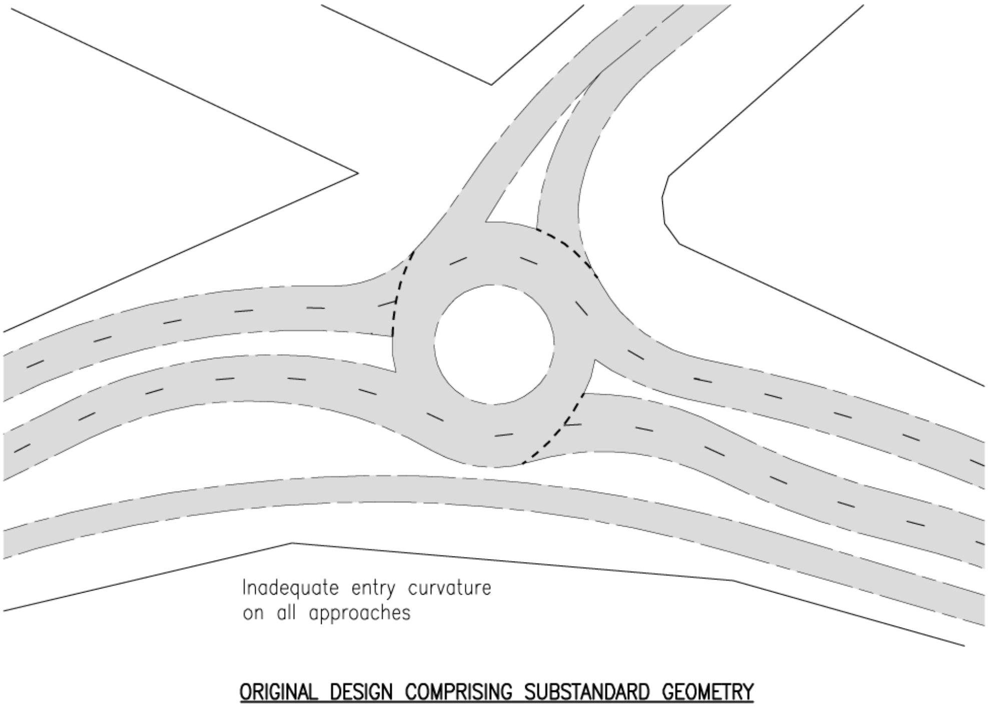
ORIGINAL DESIGN COMPRISING SUBSTANDARD GEOMETRY

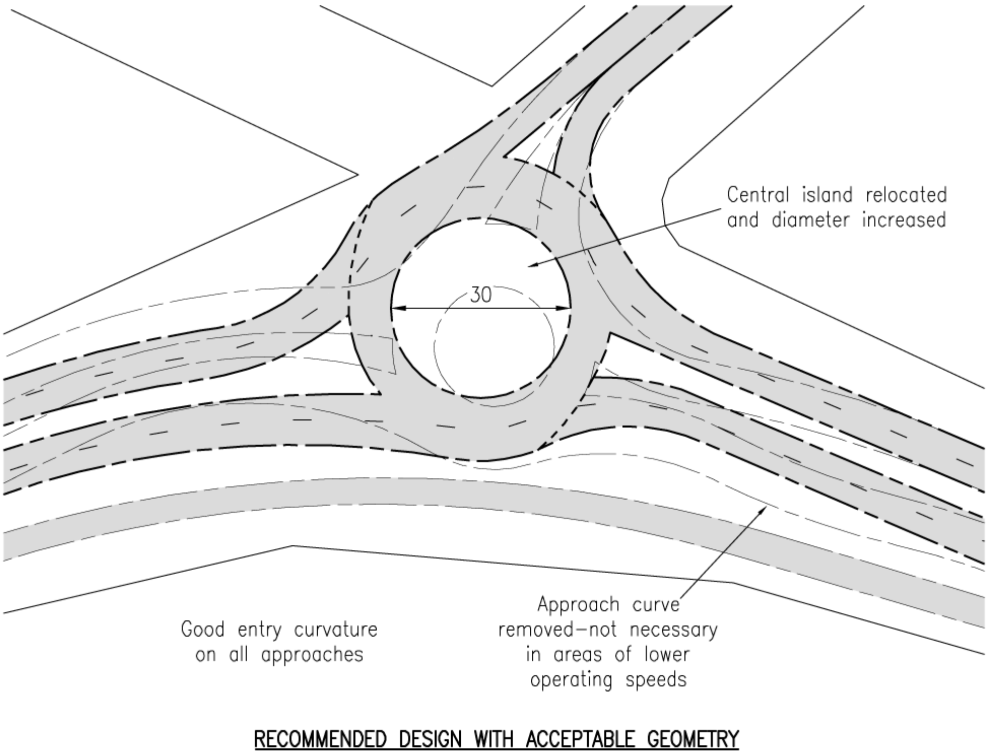


RECOMMENDED DESIGN WITH ACCEPTABLE GEOMETRY

Source: Department of Main Roads (2006).

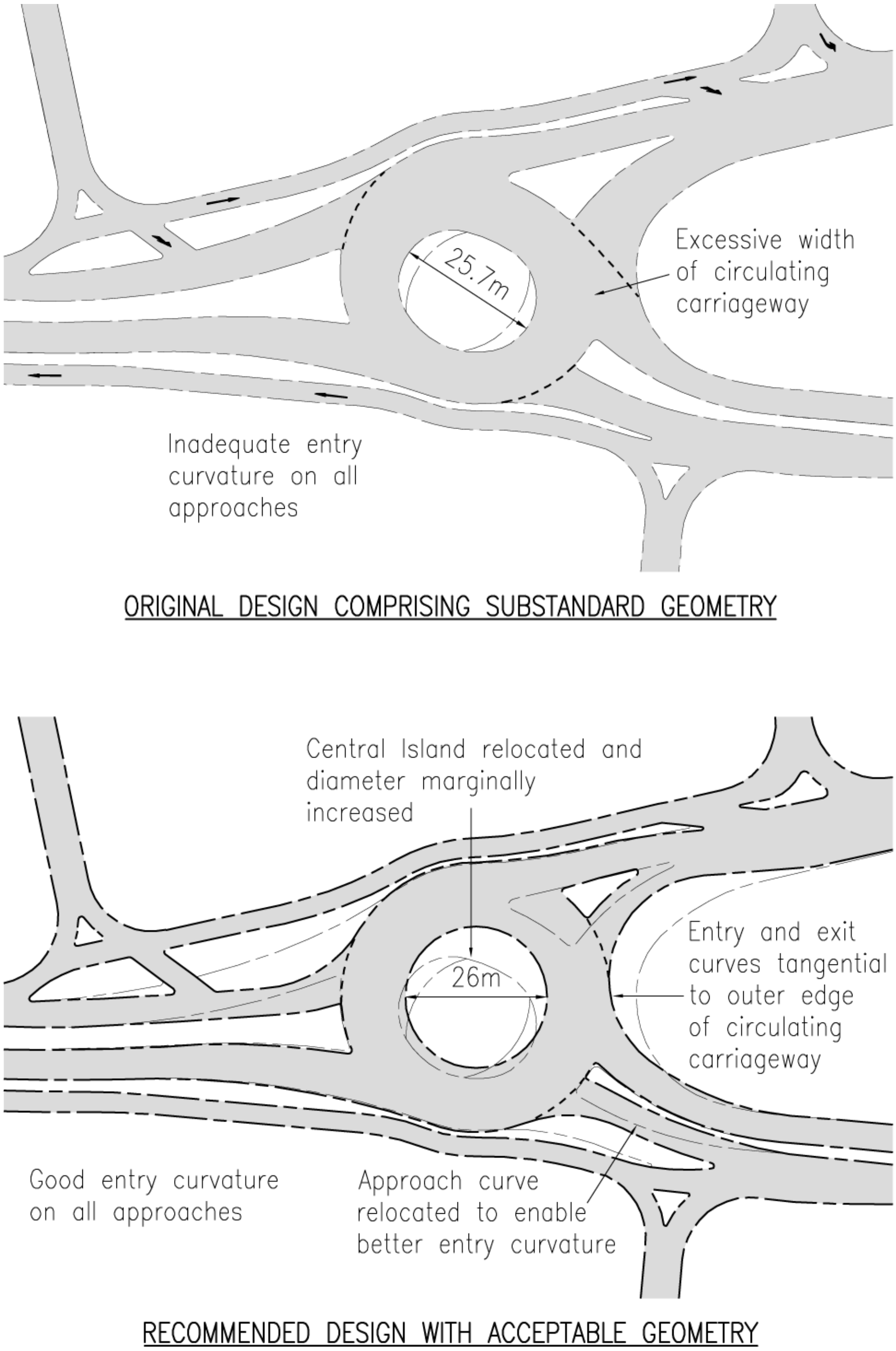
Figure C 4: Example 2 – design modifications to improve geometry





Source: Department of Main Roads (2006).

Figure C 5: Example 3 – design modifications to improve geometry



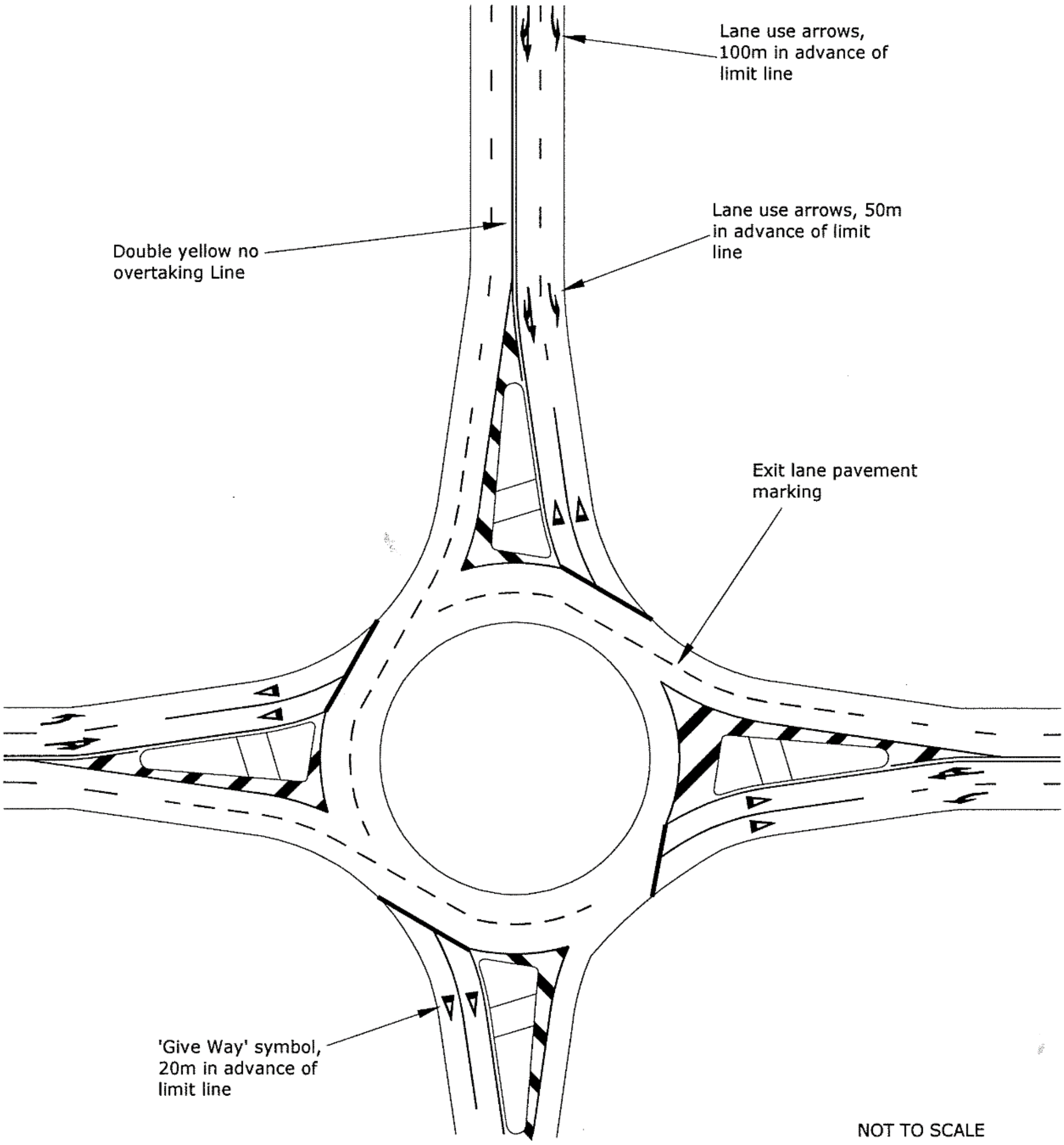
Source: Department of Main Roads (2006).

Appendix D Linemarking of Multilane Roundabouts

D.1 Introduction

The convention for linemarking at multilane roundabouts is to provide exit markings that guide circulating traffic out through the exit in lanes as shown in Figure D 1. The actual form or pattern of the lines may vary between jurisdictions. Some jurisdictions also use spiral markings (Figure D 5) within roundabouts to address particular issues, although their use of them is limited by some road authorities.

Figure D 1: An example of a typical marking scheme within a multilane urban arterial roundabout



Note: In some jurisdictions the exit pavement markings have a line pattern comprised of 9 m lines and 1 m spaces between the lines.

Source: NZ Transport Agency (2010c).

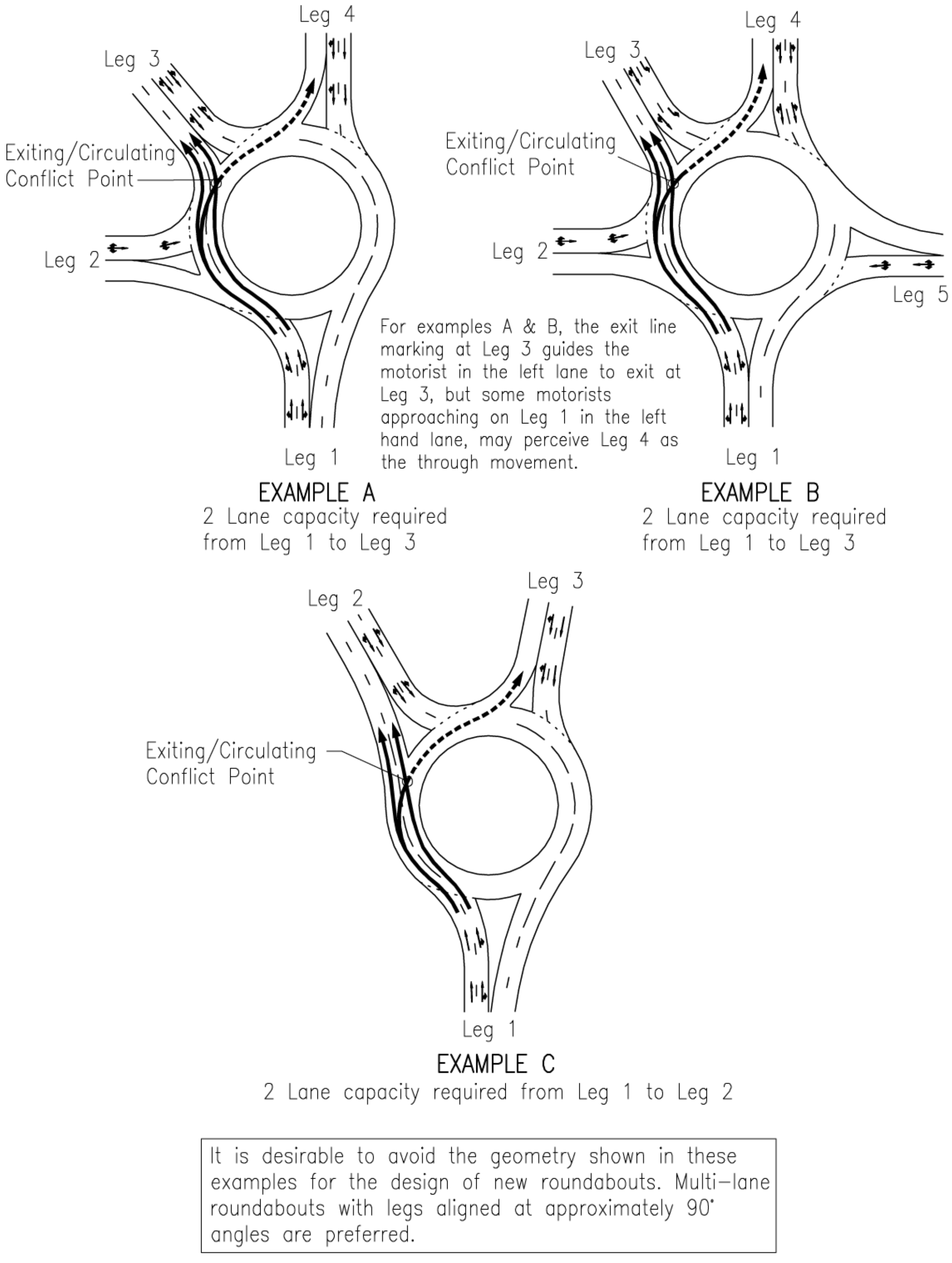
Linemarking of multilane roundabouts is achieved by the ‘exit linemarking’ or ‘Alberta linemarking’ system (Figure D 1). This system places pavement arrows on the approach legs to direct motorists into the correct lane for the particular manoeuvre they need to make. In addition, exit lines are marked to ensure that the motorist who enters the correct lane can exit without having to change lanes within the roundabout.

On multilane roundabouts with more than four legs and/or with legs aligned at significantly less or more than 90°, it can be difficult for drivers to determine to which legs the pavement arrows are pointing. Part of the difficulty is caused by:

- the pavement arrows pointing to directions one fewer than the available exit legs (e.g. Leg 1 in Example A and Legs 1 and 3 in Example B, both shown in Figure D 2)
- the pavement arrows pointing in different directions along the length of the entry curve, particularly if a long entry curve is used
- the potential conflict between the pavement arrows and the exit linemarking guiding the driver out of the circulating carriageway, e.g. in Examples A and B of Figure D 2 there is potential confusion as to whether the Leg 1 straight ahead pavement arrow refers to the movement to Leg 3 or Leg 4.

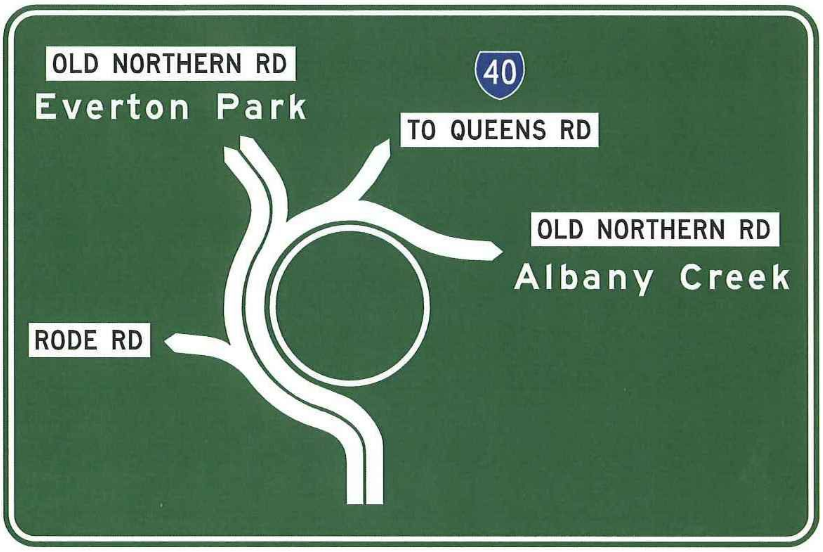
Because of this difficulty, the approach pavement arrows may not be effective in reducing exiting/circulating vehicle crashes on multilane roundabouts with more than four legs, and/or with legs aligned at significantly less or more than 90°. Such geometry is undesirable for new roundabouts and should only be considered when alternative treatments are unavailable or impracticable. Alternative treatments include forming cul-de-sacs on particular legs or creating two separate intersections. If non-standard geometry is adopted, it is recommended that appropriate advance intersection direction signs be used, an example of which is shown in Figure D 3.

Figure D 2: Appropriate lane choice can be difficult to determine on multilane roundabouts with some or all legs aligned at angles substantially more or less than 90°



Source: Department of Main Roads (2006).

Figure D 3: An example of a special advance guide sign that shows lane usage



D.2 Single-lane Exits Adjacent to Two Circulating Lanes

For multilane roundabouts, the standard exit linemarking treatment alone does not appropriately allow for single-lane exits adjacent to two circulating lanes in all cases. This typically occurs in the following instances:

- two-lane capacity is required from an entry leg to exits beyond the second exit leg
- two-lane capacity is required for a right turn
- two-lane capacity is required for a through movement from an entry leg and a left-turn leg is present at a substantial distance from the entry leg.

As a consequence of providing two-lane capacity from Leg 1 to Leg 4 of Example A in Figure D 4, there is a requirement to drop a lane at the exit preceding Leg 4, i.e. Leg 3 must be a single lane exit as shown. This helps mitigate exiting/circulating crashes at Leg 3 for traffic coming solely from Leg 1. However, a problem still exists, as motorists entering from Leg 4 or Leg 5 and exiting at Leg 3 are required to cross the exit linemarking as illustrated by Example B in Figure D 4. A similar problem will occur for Examples C and D in Figure D 4.

As a consequence of providing two-lane capacity from Leg 1 to Leg 4 (of Example A in Figure D 4), there is a requirement to provide motorists entering from Leg 4 or Leg 5 and destined for Leg 3 with an opportunity to get to the outer lane and avoid a lane change at the exit. This can be achieved by using spiral continuity linemarking as shown in Examples A and B of Figure D 5. Examples C and D of Figure D 5 illustrate this same concept for a four-legged and a three-legged, multilane roundabout respectively.

For Examples C and D of Figure D 5, there are also spirals adjacent to Legs 4 and 3, respectively. For these examples, the spiral linemarking also provides the driver already circulating on the roundabout with an opportunity to exit in either the left or right-hand lane of Leg 1. This is especially important were there are downstream accesses on Leg 1. The ability to exit in either lane will minimise lane changes for drivers turning into downstream accesses.

Spiral linemarking, however, does not completely resolve driver confusion with regard to negotiating these roundabouts. For some paths through the roundabout, drivers will need to cross the continuity line, for other paths they will need to follow it. Examples of this are described below.

D.2.1 Examples A and B of Figure D 5

When travelling from Leg 1 to Leg 4 in the inner lane, a motorist is to cross the continuity line.

- When travelling from Leg 5 to Leg 3 or from Leg 4 to Leg 3, a motorist must follow the continuity line.
- When travelling from Leg 5 to Leg 5 (i.e. a U-turn from Leg 5), a motorist is to cross the continuity line.
- When travelling from Leg 5 to Leg 4 or from Leg 4 to Leg 4 (i.e. a U-turn from Leg 4), a motorist can either cross or follow the continuity line.

D.2.2 Example C of Figure D 5

- When travelling from Leg 1 to Leg 4 on the inner lane, a motorist is to cross the continuity line.
- When travelling from Leg 4 to Leg 3, a motorist is to follow the continuity line.
- When travelling from Leg 3 to Leg 3 (i.e. a U-turn from Leg 3), a motorist is to cross the first continuity line, then follow the second continuity line.
- When travelling from Leg 4 to Leg 4 (i.e. a U-turn form Leg 4), a motorist can either follow or cross the continuity line.

D.2.3 Example D of Figure D 5

- When travelling from Leg 1 to Leg 3 on the inner lane, a motorist is to cross the continuity line.
- When travelling from Leg 2 to Leg 2 (i.e. a U-turn from Leg 2), a motorist is to cross the first continuity line, then follow the second continuity line.
- When travelling from Leg 3 to Leg 2, a motorist is to follow the continuity line.
- When travelling from Leg 3 to Leg 3 (i.e. a U-turn from Leg 3), a motorist can either follow or cross the continuity line.

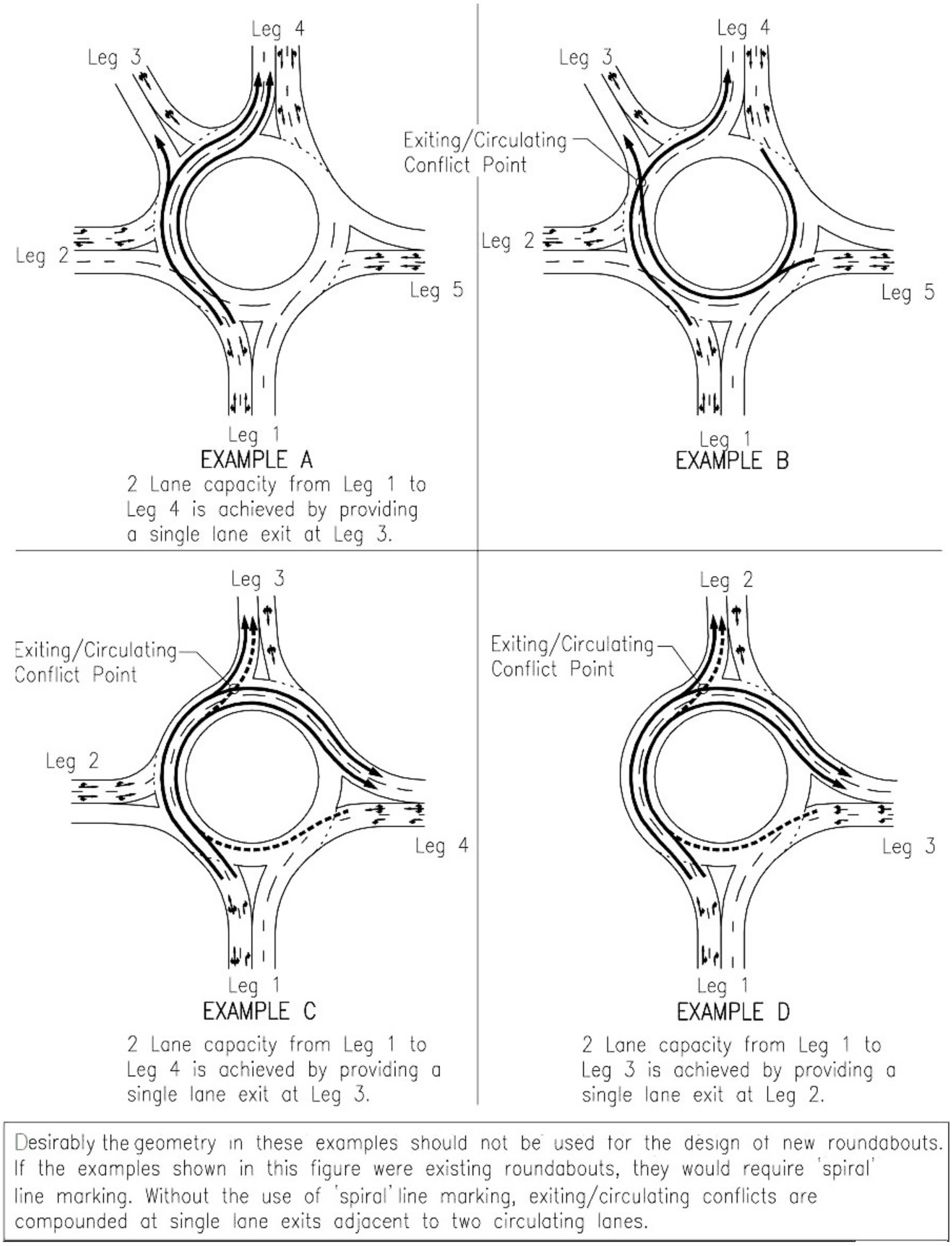
D.2.4 Conclusion

It is very difficult to advise drivers of the above requirements for all movements through these roundabouts, particularly with regard to when/how a driver is required to follow the spiral linemarking, i.e. change from the inner circulating lane to the outer circulating lane for the movements above. Advance intersection direction signs do not show the required action in this case. For this reason, drivers faced with the spiral linemarking may be confused as to whether to cross the linemarking or not.

For the above reasons, two-lane capacity from an entry leg to an exit beyond the second exit leg is undesirable and should only be considered for existing roundabouts where there is a capacity problem. New roundabouts should desirably be designed so that there is no need for the use of spiral linemarking.

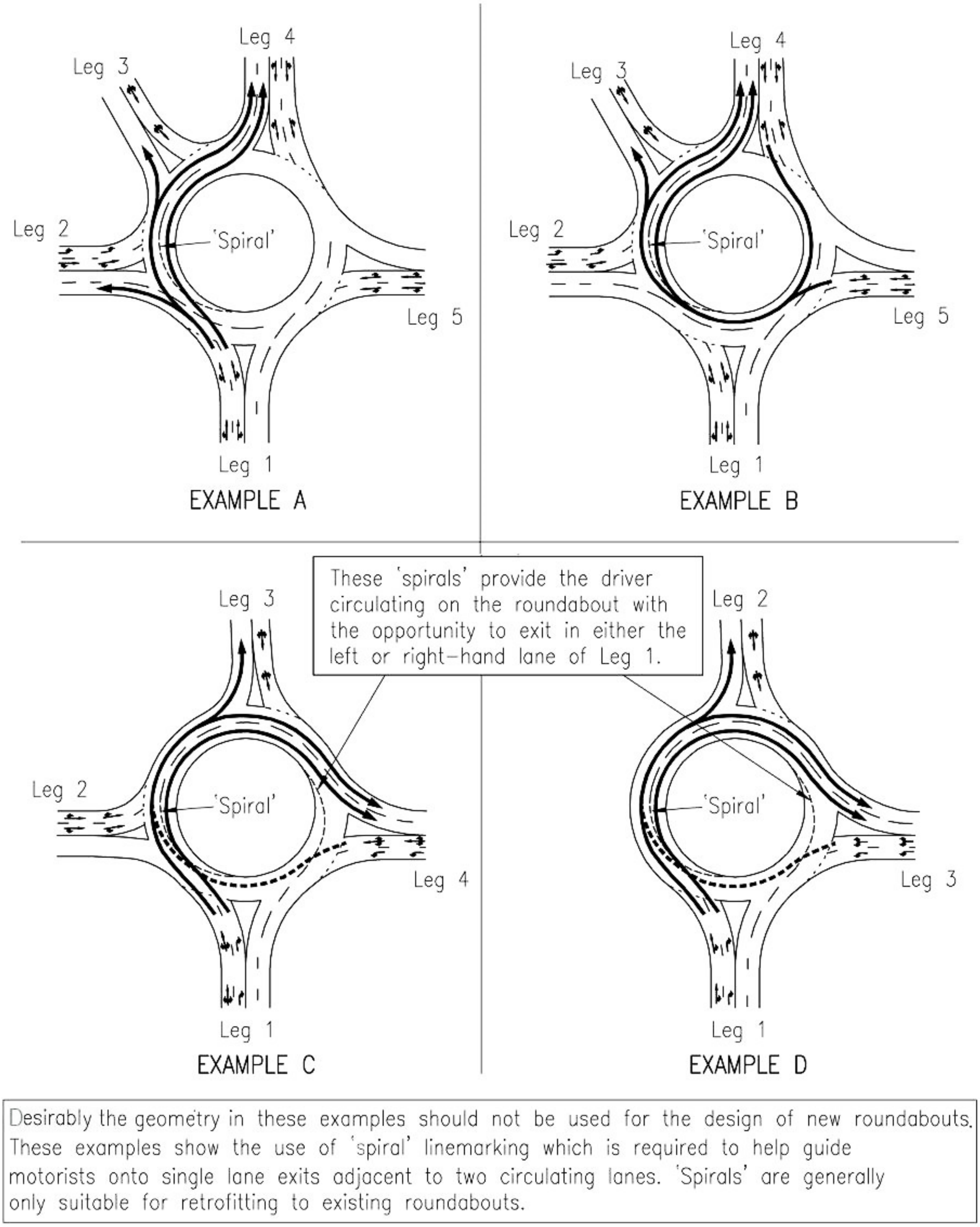
Spiral linemarking should only be considered as a solution to minimising operational problems on existing roundabouts where no other solution is feasible, and careful consideration needs to be given to the use/provision of spiral markings, with advice being sought from the relevant jurisdiction.

Figure D 4: Examples showing potential conflicts arising without the spiral linemarking system



Source: Department of Main Roads (2006).

Figure D 5: Examples showing the use of the spiral linemarking system for the examples shown in Figure D 4



Source: Department of Main Roads (2006).

Appendix E Extended Design Domain (EDD) for Entry Path Radii

The maximum entry path radii in Section 4.5.3 are based on achieving a desired maximum entry speed for vehicles which will generally minimise crash rates. The following entry path radii in Table E 1 are larger than those in Section 4.5.3 and may be acceptable to use where existing site constraints result in adoption of the normal design domain (NDD) values being unachievable.

Table E 1: EDD maximum entry path radii for one and two-lane roundabouts

Desired driver speed on the leg prior to the roundabout (km/h)	Maximum entry path radius (m)	
	Single-lane entries(1) Two-lane entry – staying in correct lane(2)	Two-lane entry – cutting across lanes(3)
≤ 40	100	1.9 x actual entry path radius when staying in correct lane(4)
50	80	1.8 x actual entry path radius when staying in correct lane(4)
60	70	1.6 x actual entry path radius when staying in correct lane(4)
70	70	1.5 x actual entry path radius when staying in correct lane(4)
≥ 80	≤ 55	1.5 x actual entry path radius when staying in correct lane(4)

1 *Construction of the entry path of a single-lane entry for roundabouts comprising one or two circulating lanes is given in Figure 4.5.*
2 *Construction of the entry path of a two-lane entry – staying in the correct lane for a two-lane roundabout is given in Figure 4.6.*
3 *Construction of the entry path of a two-lane entry – cutting across lanes for a two-lane roundabout is given in Figure 4.7.*
4 *Radius of the entry path for drivers staying in the correct lane as determined in Figure 4.6.*

Commentary 1

C1.1 General

Roundabouts operate as a series of separate T-intersections. They are a form of unsignalised intersection where all approaching drivers are required to slow down or stop, and to look for an acceptable gap in the circulating traffic so that they can enter in a safe manner. The behaviour of the driver is related to the geometry of the roundabout and prevailing traffic conditions. All drivers approaching a roundabout potentially have to give way and this, combined with a design that physically restricts the speed at which drivers can enter and negotiate the treatment, generally results in a superior safety performance.

Higher relative speeds of vehicles result in higher multiple-vehicle crash rates and greater crash severity. Basic at-grade intersections (cross and T-types) will generally record significantly higher multiple vehicle crash rates than roundabouts.

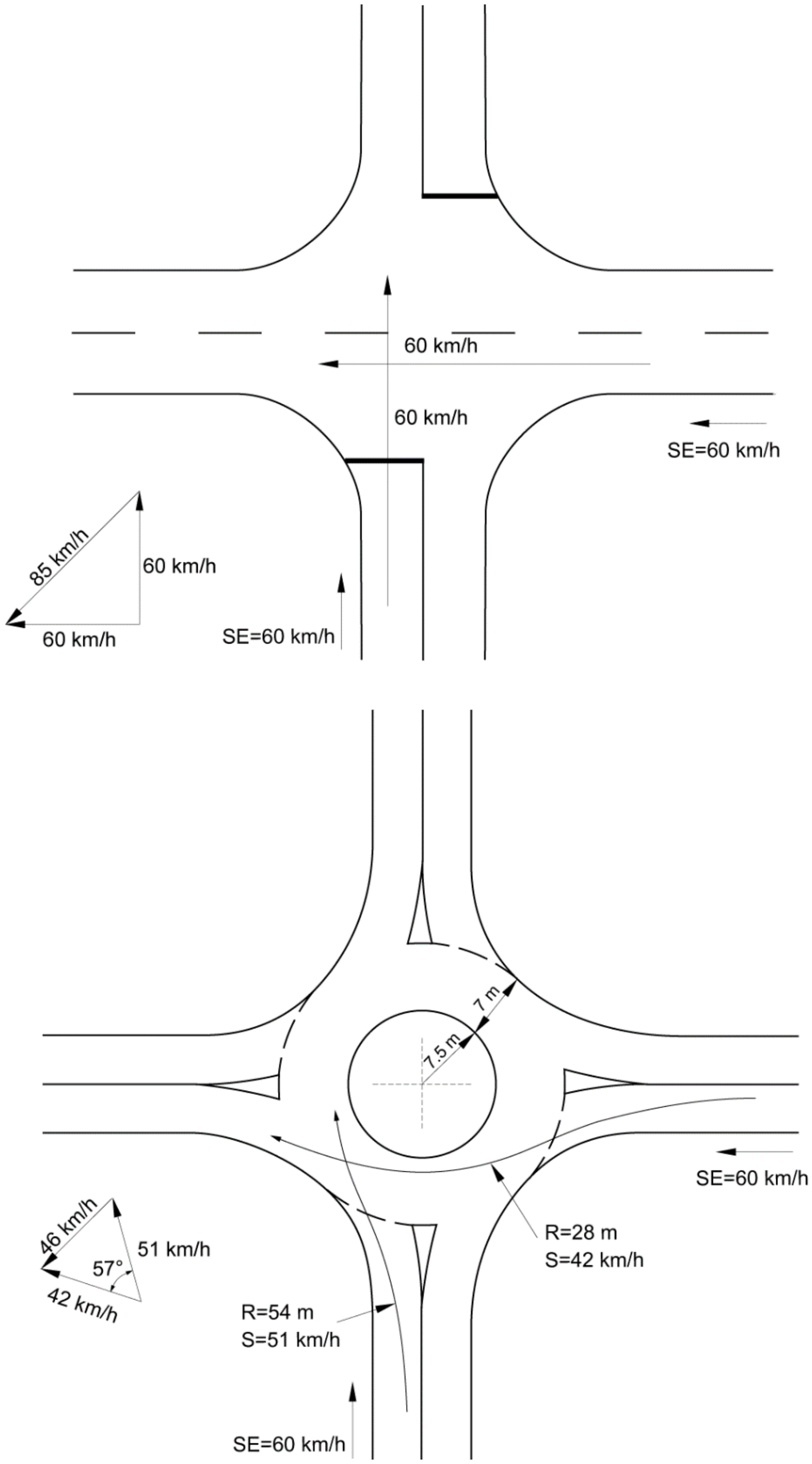
The safety performance of roundabouts is dependent on good design, where the entry curvature limits the speed at which drivers can enter the circulating carriageway. While roundabouts generally have a much lower crash rate than other forms of intersection, some roundabouts have very high crash rates involving minor injuries and property damage only. The main benefit is a large reduction in crash severity as serious injuries and fatalities are rare due to lower relative speed of colliding motor vehicles. This reduced severity should be allowed for in economic evaluation of their benefits.

Figure C1 1 shows two intersection treatments for roadways that cross at a 90°. The desired speed on each of the roads is 60 km/h. The upper diagram in Figure C1 1 shows a typical at-grade intersection treatment. The potential relative speed of vehicles on adjacent roadways at this intersection is 85 km/h. Some drivers will attempt to enter these intersections at a much higher speed than they should, e.g. up to 60 km/h, in spite of a traffic control device requiring them to yield or to stop.

The lower diagram in Figure C1 1 shows a roundabout at the intersection of these roads. The relative speed of entering and circulating vehicles at this roundabout is 46 km/h. This value is much lower than the 85 km/h for the at-grade intersection.

Well-designed roundabouts achieve a lower relative speed of vehicles on crossing roads primarily because of the presence of entry curvature. Conversely, a poorly designed roundabout with little entry curvature results in high speeds through the roundabout, creating high relative speeds between vehicles. Multiple-vehicle crash rates at these roundabouts can actually be higher than for an equivalent at-grade intersection. Therefore, it is important that designers give special attention to the design of the geometry of roundabouts.

Figure C1 1: Two intersection treatments for roadways that cross at a 90-degree angle



Source: Department of Main Roads (2006).

C1.2 Pedestrians and Cyclists

It should be noted that, at locations where there are high levels of cycle and pedestrian traffic, roundabouts may not be the most appropriate intersection treatment and alternative treatments, particularly traffic signals, should be considered.

Studies and experience have not confirmed that roundabouts are less safe for pedestrians than other intersection types. However, there is anecdotal evidence to suggest that children and elderly pedestrians do feel less safe at roundabouts, particularly at exits. This is because, unlike traffic signals, roundabouts do not give priority to pedestrians over through traffic.

Various studies have indicated that roundabouts, particularly those which have more than one lane in the circulating roadway, are markedly less safe for cyclists than for other road users.

In a study of the reported crashes at roundabouts in New South Wales by Robinson (1998) it was found that:

- 6% of those injured at intersections were cyclists compared with 18% at roundabouts
- at non-metropolitan roundabouts, 32% of those injured in two-party crashes were cyclists
- cyclists were responsible for 16% of the crashes in which they were involved.

Similarly, Allott and Lomax (1993) found cyclist crash rates at roundabouts were up to 15 times those for cars and two to three times those for cyclists at traffic signals.

Robinson (1998) confirmed the roundabout entry problem involving cyclists more recently with the finding that 70% of two-party incidents resulting in injury, involved circulating cyclists or motorcyclists being hit by entering motorists. These studies confirm that motorists often do not see cyclists approaching in the roundabout or at least misjudge their speed and relative position.

The size and layout of roundabouts are important factors. In general, small roundabouts with relatively slow traffic speeds, and with a circulating carriageway narrow enough to prevent motor vehicles overtaking cyclists, present no special risks for cyclists – Brude and Larsson (1996), Van Minnen (1996) and Balsiger (1992).

Experience in Queensland has revealed that:

- cyclists are involved as circulating vehicles in approximately 13% of the entering/circulating vehicle crashes in Queensland and are over-represented in these crashes
- reducing the relative speed between entering and circulating vehicles, minimising the number of circulating lanes, and maximising the distance between approaches reduces the entering/circulating vehicle crash rates at roundabouts. These design concepts will also minimise entering/circulating vehicle crashes involving cyclists.

The results of various studies indicate that a separated cycle path, located outside of the circulating carriageway, is the safest design when there are high vehicle flows. Separate cycle paths have been found to be safer than a bicycle lane within the circulating roadway, particularly at highly trafficked roundabouts. This has the added advantage of restricting widths through the roundabout, enabling better entry curvature to be obtained. However, experienced commuter cyclists are not likely to use paths around the periphery of roundabouts because of the delay and inconvenience. Studies have also shown that the effect of the signalisation at roundabouts has resulted in an overall reduction in crashes involving cyclists.

The increased risk to cyclists needs to be given due consideration when weighing up the advantages and disadvantages of adopting a roundabout treatment at a particular location. The choice will often depend on the proportion of cyclists and other non-motorised road users expected to use the roundabout, along with other factors such as the functional classification of the roads involved and the overall traffic management strategy to be adopted.

It is important to understand that the risk to cyclists and pedestrians depends on the type of roundabout. While a single-lane, low-speed urban roundabout may be satisfactory for pedestrians and cyclists, multilane roundabouts, or poorly designed single-lane roundabouts with inadequate entry curvature that promotes high entry speeds, are less safe for cyclists and pedestrians.

In summary, it is not the volume of cyclist or pedestrian traffic that makes conditions at roundabouts unsuitable for pedestrians and cyclists, but the volume and speed of motor traffic and the number of lanes.

[Back to body text]

Commentary 2

Practitioners are referred to Arndt and Troutbeck (1998) which highlights five major crash types (Appendix A) identified in the roundabout study and details how a number of geometric parameters at roundabouts can be designed to minimise crash rates. Often, the effect of one geometric parameter on crash rates cannot be considered in isolation because it can affect a number of other parameters. For example, increasing the number of legs for a given roundabout diameter will usually change the approach carriageway geometry because less room is available to obtain adequate approach curvature. This interrelationship needs to be considered when choosing appropriate values of the various geometric parameters.

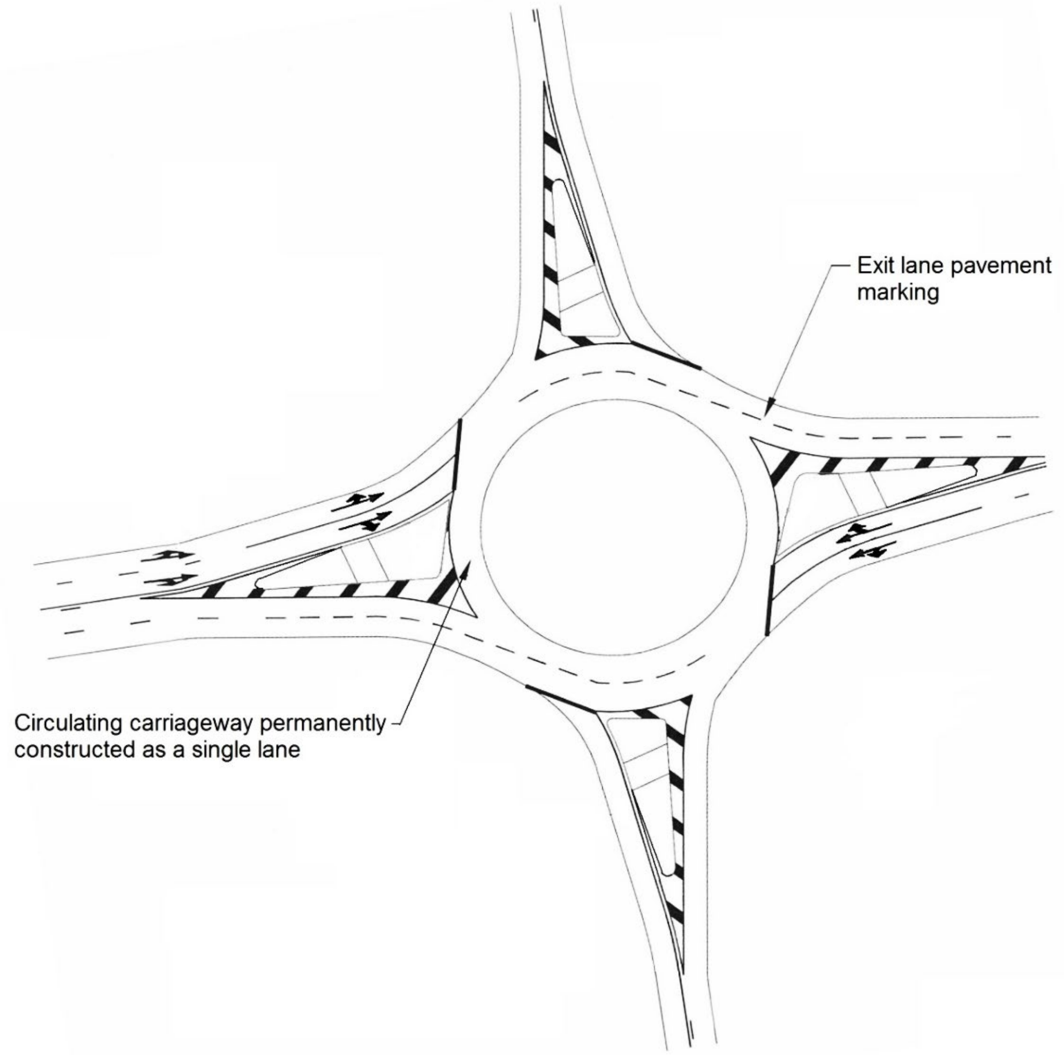
[Back to body text]

Commentary 3

The circulating carriageway of a roundabout does not have to provide a consistent number of lanes throughout. They can vary depending on the number of entry lanes that serve the particular section of the circulating carriageway. For example, Figure C3 1 shows a roundabout where the circulating carriageway is to be permanently constructed with reduction to one lane on the circulating carriageway. The width of the circulating carriageway is based on the swept path of the design vehicle plus clearances to kerbs. This treatment is appropriate where there is no likelihood that a second lane will be required in the medium term, say 10 years.

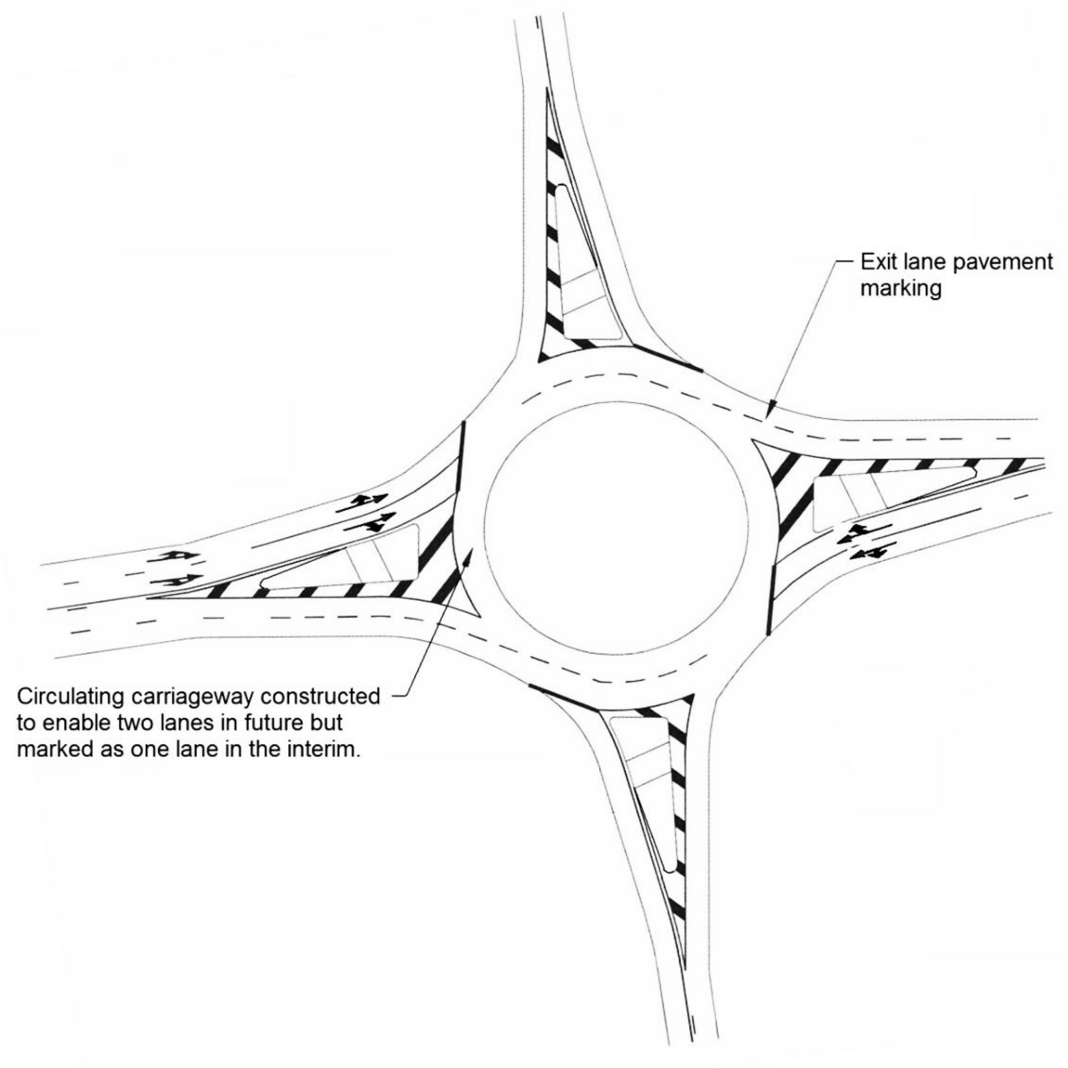
Where traffic modelling and analysis indicate that two lanes will be required in the subject section of the circulating carriageway in the medium term, consideration should be given to constructing two lanes initially, and painting the pavement as one circulating lane in the interim, as shown in Figure C3 2. This strategy will avoid the need to undertake construction within the roundabout under traffic when the two lanes are needed in future. The extra lane may be required when there is a need to increase through capacity on the single-lane approaches (by providing an additional lane) or to increase the capacity of the right-turn movements on the two-lane approaches.

Figure C3 1: Multilane roundabout permanently constructed with reduction to one lane on circulating carriageway



Source: Based on NZ Transport Agency (2010c).

Figure C3 2: Multilane roundabout showing interim reduction to one lane in circulating carriageway



Source: Based on NZ Transport Agency (2010c).

[Back to body text]

Austroads' **Guide to Road Design Part 4B: Roundabouts** provides road designers and other practitioners with guidance on the geometric design of roundabouts. The Guide covers design principles and procedures, and guidelines for all of the key elements of a roundabout, enabling practitioners to develop safe and efficient layouts. Part 4B also provides information on pedestrian and cyclist treatment at roundabouts and related topics such as pavement markings, signs and landscaping.

Guide to Road Design Part 4B

Austroads

Austroads is the association of Australasian road and transport agencies.

www.austroads.com.au