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Guide to Road Design
Part 4B: Roundabouts
Guide to Road Design Part 4B: Roundabouts

Summary
The Guide to Road Design – Part 4B: Roundabouts provides road designers and other practitioners with guidance on the geometric design of roundabouts. However, the guide generally contains only advice that is specific to the design of roundabouts and should therefore be used in conjunction with three other parts of the Guide to Road Design that relate to the design of intersections, namely:

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

Part 4B covers design principles and procedure, and provides guidelines for all the key elements thus enabling practitioners to develop safe and efficient layouts. It also provides information on pedestrian and cyclist treatments at roundabouts and related topics such as pavement markings, signs, and landscaping. However, designers should refer to all other relevant parts of the Guide to Road Design and to the Guide to Traffic Management – Part 6: Intersections, Interchanges and Crossings (Austroads 2007) which covers traffic management and road use aspects of roundabouts.

Part 4B includes a new design method for roundabouts that focuses on the entry curvature to achieve a reduction in vehicle approach speeds rather than applying the ‘deflection method’ used in previous Australian guides.

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, road lighting, landscaping

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- promoting harmonisation, consistency and uniformity in road and related operations
- undertaking strategic research on behalf of road agencies and communicating outcomes
- promoting improved and consistent practice by road agencies.

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- Roads Corporation Victoria
- Department of Transport and Main Roads Queensland
- Main Roads Western Australia
- Department for Transport, Energy and Infrastructure South Australia
- Department of Infrastructure, Energy and Resources Tasmania
- Department of Planning and Infrastructure Northern Territory
- Department of Territory and Municipal Services Australian Capital Territory
- Department of Infrastructure, Transport, Regional Development and Local Government
- Australian Local Government Association
- New Zealand Transport Agency.

The success of Austroads is derived from the collaboration of member organisations and others in the road industry. It aims to be the Australasian leader in providing high quality information, advice and fostering research in the road sector.
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1 INTRODUCTION

1.1 Purpose

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

The purpose of the *Guide to Road Design – Part 4: Intersections and Crossings – General* (Austroads 2009b), is to provide guidance to road designers on the geometric design of all types of road intersections and crossings. The Guide comprises four parts:

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

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 that Part 4 is one of eight guides that comprise the Austroads *Guide to Road Design*. 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.

![Figure 1.1: Flow chart of the Guide to Road Design](image-url)

Note: Part 6 of the *Guide to Road Design* comprises three parts, namely:

- **Part 6: Roadside design, safety and barriers** (Austroads 2009e)
- **Part 6A: Pedestrian and cyclist paths** (Austroads 2009f)
- **Part 6B: Roadside environment** (Austroads 2009g).

*Figure 1.1: Flow chart of the Guide to Road Design*
1.2 Scope of this Part

The purpose of Part 4B: Roundabouts is to provide in relation to roundabouts:

- 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.

Part 4B 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 Guide to Road Design and the Guide to Traffic Management, Part 4B 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 (www.austroads.com.au).

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 that the community should not penalise people with death or serious injury when they do make mistakes. In a safe system, therefore, roads (and vehicles) should be designed to reduce the incidence and severity of crashes when they inevitably occur.

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

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

The Safe System approach is recognised as the guiding principle for road safety in the current Australian Road Safety Action Plan.

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 Guide to Road Safety (Austroads 2006–2009).

1.4 Road Design Objectives

Road design objectives are discussed in Section 1.1 of the Guide to Road Design – Part 2: Design Considerations (Austroads 2006b), and the objectives also apply to the design of intersections and crossings, including roundabouts.
1.5 Traffic Management at Roundabouts

As intersection design is influenced by traffic management considerations road designers should be familiar with traffic management considerations associated with roundabouts that are covered in Section 4 of the Guide to Traffic Management – Part 6: Intersections, Interchanges and Crossings (Austroads 2007). This addresses the use of roundabouts as a treatment, road space allocation, lane management and the traffic management aspects of functional design.

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 Guide to Traffic Management – Part 5: Road Management (Austroads 2008a) which covers mid-block traffic management and provides guidance on access management, road space allocation, lane management and speed limits.

Table 3.3 of the Guide to Traffic Management – Part 6: Intersections, Interchanges and Crossings (Austroads 2007) summarises general issues relating to cyclists at intersections. Some of these issues also 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 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 at 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 as follows:

- 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.

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 traffic or right-turning traffic and access for some pedestrians may be reduced. 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 motor vehicle drivers to scan for cyclists, and consequently minimise cyclist crashes. Special 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.

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 versatility of roundabouts has been proven and they can be a satisfactory treatment at a wide range of intersection sites in low and high-speed environments such as:

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

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.mainroads.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 (1998) for detailed information.

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

Crash models for roundabouts in New Zealand have also been developed (Turner et al 2006), a brief description of which is in Appendix A.

1.7 Traffic Capacity of Roundabouts

The performance of roundabouts is covered in the Guide to Traffic Management – Part 3: Traffic Studies and Analysis (Austroads 2009h) which 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 (Guide to Traffic Management – Part 3: Traffic Studies and Analysis (Austroads 2009h) and Part 4: Network Management (Austroads 2009i)). 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, to:

- 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 4.4 of the Guide to Traffic Management – Part 6: Intersections, Interchanges and Crossings (Austroads 2007). Generally, traffic engineers and road designers should never set out to provide signalised roundabouts at greenfield sites. If an existing roundabout is performing poorly on one or two approaches during peak periods then 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 rare 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.

1.9 Significant Change from the Guide to Traffic Engineering Practice – Part 6: Roundabouts

A most significant change in this guide compared to the previous Austroads guide is that deflection is no longer used as a fundamental parameter in achieving control of the speed of vehicles at roundabouts. The method in this guide controls the 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 DESIGN PRINCIPLES AND PROCEDURE

2.1 Terminology

Figure 2.1 illustrates the geometric elements of a roundabout and the terminology applied to them.
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 desirably be limited to four (although up to six may be used at an appropriately designed single-lane roundabout)
- legs should desirably intersect at approximately 90°, especially for multi-lane roundabouts
- it is essential that appropriate entry curvature is used to limit the entry speed
- 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
- sufficient entry, circulating and exit lanes should be provided to ensure that the roundabout operates at an appropriate level of service.

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 illustrated in Section 6 of the Guide to Traffic Management – Part 6: Intersections, Interchanges and Crossings (Austroads 2007), 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

The Guide to Road Design – Part 4: Intersections and Crossings – General (Austroads 2009b) provides a general design process that applies to all intersections (Section 3 and Figure 3.1 of Part 4) including roundabouts. This process covers considerations that are essential for intersection design such as traffic data, future development that may influence a design and constraints on design (e.g. topography, budget).

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 (Guide to Traffic Management – Part 3: Traffic Studies and Analysis (Austroads 2009h)). The number of lanes is a basic input to the design process.
This section provides a 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 between two local residential streets may be a relatively simple exercise where traffic analysis is unnecessary and 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, which provides considerations and cross-references relating to the design steps in Figure 2.2.
Step 1 – Assemble general design criteria:
- design vehicle & turning radius
- number of entry, circulating and exit lanes
- queue lengths on approaches
- special needs – pedestrians, cyclists, over-dimensional vehicles, buses and trams

Step 2 – Identify site controls such as:
- utilities
- trees
- monuments
- parking
- access etc

Step 3 – Establish the area available for the roundabout and draw the alignment of approach roads and mid-block cross sections (approach and departure lanes)

Step 4 – Select a trial central island diameter and width for the circulating carriageway

Step 5 – Draw, in a trial position, the central island and circulating carriageway

Step 6 – Draw trial entry and exit leg geometry for all legs including the vertical grading of approaches. Include facilities for pedestrians and cyclists.

Step 7 – Are swept paths satisfactory?

Step 8 – Are entry path radii less than the maximum values in Table 4.2 and is approach grading satisfactory?

Step 9 – Are sight distances satisfactory?

Step 10 – Complete design detail

Figure 2.2: Design procedure for roundabouts

Austroads 2009
Table 2.1: Design procedure – considerations and cross-references

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<th>Step</th>
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<td>Central island.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Circulating carriageway.</td>
<td>Section 4.6, Table 4.3 and Table 4.4.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 5</td>
<td>Draw central island and circulating</td>
<td></td>
</tr>
<tr>
<td></td>
<td>carriageway in trial position</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Check that inscribed circle can accommodate all</td>
<td>Guide to Road Design – Part 3: Geometric Design (Austroads 2009a).</td>
</tr>
<tr>
<td></td>
<td>legs.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>If inscribed circle is too close to road</td>
<td>Guide to Road Design – Part 6B: Roadside Environment (Austroads 2009g).</td>
</tr>
<tr>
<td></td>
<td>trailed.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Clearance from kerbs to boundary must accommodate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>drainage, existing and proposed utilities,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>pedestrian and bicycle paths etc.</td>
<td></td>
</tr>
<tr>
<td>Step</td>
<td>Consideration</td>
<td>Cross-reference</td>
</tr>
<tr>
<td>------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>Mid-block cross-section should be drawn and extended to the roundabout to provide a reference for entry path.</td>
<td>Section 4.10.2.</td>
</tr>
<tr>
<td></td>
<td>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.</td>
<td>Section 5.3.</td>
</tr>
<tr>
<td></td>
<td>Where bicycle lane is provided on approach consider appropriate treatment.</td>
<td>Section 5.3.</td>
</tr>
<tr>
<td></td>
<td>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.</td>
<td>Figure 2.1.</td>
</tr>
<tr>
<td></td>
<td>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.</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Check swept paths of the design vehicle for all traffic movements including the circulating carriageway.</td>
<td>Section 5 of the Guide to Road Design – Part 4: Intersections and Crossings – General (Austroads 2009b).</td>
</tr>
<tr>
<td></td>
<td>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.</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Check that the maximum entry path radii have been achieved.</td>
<td>Section 4.5.5 and Table 4.2.</td>
</tr>
<tr>
<td></td>
<td>Draw entry path radii in accordance with Section 4.5.5. 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.</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Check that sight distances are satisfactory</td>
<td>Section 3 of the Guide to Road Design – Part 4A: Unsignalised and Signalised Intersections (Austroads 2009c).</td>
</tr>
<tr>
<td></td>
<td>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. Check sight distance for driver from a position at the holding line of the roundabout.</td>
<td>Figure 3.1 and Table 3.1.</td>
</tr>
</tbody>
</table>
3 SIGHT DISTANCE

3.1 Introduction
Roundabouts must be designed to provide the same approach sight distance (ASD) as other intersections (Section 3, Guide to Road Design – Part 4A: Unsignalised and Signalised Intersections (Austroads 2009c)). 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 desirably the circulating carriageway. Adequate ASD should be provided to the holding line/s. Where this cannot be achieved and, as an absolute minimum, ASD to the (approach) nose of the splitter island should be provided.

ASD is defined and discussed in Section 3 of the Guide to Road Design – Part 4A: Unsignalised and Signalised Intersections (Austroads 2009c). The required ASD is based on the speed of drivers 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 the Guide to Road Design – Part 4A: Unsignalised and Signalised Intersections (Austroads 2009c) that respectively provide ASD values and corrections that should be applied to the values to allow for gradient on the approach.
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
- 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 to 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**

<table>
<thead>
<tr>
<th>85th percentile speed (km/h) on the approach immediately to the right, or on the circulating roadway</th>
<th>Criterion 2 sight distance (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local residential street roundabout critical acceptance gap 4 s</td>
<td>Arterial road roundabout critical acceptance gap 5 s</td>
</tr>
<tr>
<td>-----------------------------------------------------------------------------------------------</td>
<td>--------------------------------</td>
</tr>
<tr>
<td>20</td>
<td>22</td>
</tr>
<tr>
<td>30</td>
<td>33</td>
</tr>
<tr>
<td>40</td>
<td>44</td>
</tr>
<tr>
<td>50</td>
<td>55</td>
</tr>
<tr>
<td>60</td>
<td>67</td>
</tr>
</tbody>
</table>
3.2.3 Criterion 3

It is also desirable that a driver (car A) approaching a roundabout is able to see other entering vehicles (e.g. 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 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.

3.3 Truck Stopping Sight Distance

The sight distance requirements for roundabouts discussed above for intersections are based on cars. However, to ensure that trucks approaching the roundabout at the 85th percentile operating speed of trucks are able to stop safely, truck stopping sight distance (TSSD) 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 TSSD 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.

Values for TSSD for trucks and corrections for grade are given in Section 3 of the Guide to Road Design – Part 4A: Unsignalised and Signalised Intersections (Austroads 2009c).
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 *Guide to Traffic Management – Part 6: Intersections, Interchanges and Crossings* (Austroads 2007). This section provides guidance on the method and parameters to be used in the geometric design of roundabouts.

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 multi-lane roundabouts as it can create conflict at exits. Drivers can also experience difficulty in the appropriate lane choice required for left, through and right-turns on some approaches (Section 4.6.2 and Commentary 18, *Guide to Traffic Management – Part 6: Intersections, Interchanges and Crossings* (Austroads 2007)).

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).

A single-lane roundabout may be provided initially and upgraded in the future (say 10 to 15 years) to a dual-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 (*Guide to Traffic Management – Part 3: Traffic Studies and Analysis* (Austroads 2009h)) 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 multi-lane 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 multi-lane 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 multi-lane 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
- 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 *Guide to Traffic Management – Part 6: Intersections, Interchanges and Crossings* (Austroads 2007) and geometric design details are provided in the *Guide to Road Design – Part 4A: Unsignalised and Signalised Intersections* (Austroads 2009c).

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
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.

Roundabouts on designated bicycle routes should be provided with bicycle lanes on approaches and through the roundabouts (Section 5.3). Where a roundabout is constructed at a T-intersection between arterial roads a bypass path for cyclists may be constructed across the top of the T-intersection.

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 need to be used 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 4.15) 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 \( \leq 80 \text{ km/h} \). 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. 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 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 that the open drain does not create a hazard. Refer to the *Guide to Road Design – Part 3: Geometric Design* (Austroads 2009a) for guidance on forgiving open drain profiles. On very large roundabouts planting can be provided in the depressed area, including large trees.
On smaller roundabouts that have a central island diameter less than (say) 20 m to 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 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.

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 say 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 Minimum 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 to 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 is a guide for selection of the minimum central island radius for a circular roundabout. The criteria in the table should enable acceptable entry geometry in accordance with Table 4.2 to be provided on each leg (Arndt 2008). The desirable values given in Table 4.1 should be used whenever possible as they generally produce lower overall crash rates than those produced by the absolute values (Notes 2 and 3 in Table 4.1).

The criteria in this table are based on obtaining a sufficient roundabout size to limit the values of the various roundabout safety parameters recommended in Arndt (1998), in order to minimise the various crash types (Appendix C).

<table>
<thead>
<tr>
<th>Desired driver speed on the fastest leg prior to the roundabout (km/h)</th>
<th>Minimum central island radius of a single-lane roundabout (m)</th>
<th>Minimum central island radius of a two-lane roundabout (m)</th>
<th>Speed reduction treatments required prior to the entry curve¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Absolute</td>
<td>Desirable</td>
<td>Absolute</td>
</tr>
<tr>
<td>≤ 40²</td>
<td>5¹</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>50²</td>
<td>8</td>
<td>11</td>
<td>8</td>
</tr>
<tr>
<td>60³</td>
<td>10</td>
<td>12</td>
<td>14</td>
</tr>
<tr>
<td>70³</td>
<td>12</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>80³</td>
<td>14</td>
<td>22</td>
<td>20</td>
</tr>
<tr>
<td>≥ 90³</td>
<td>14</td>
<td>22</td>
<td>20</td>
</tr>
</tbody>
</table>

1. Refer to Section 4.5.2 for the various types of speed reduction treatments.
2. The desirable minimum central island radii listed for these speeds generally provide sufficient size splitter islands for storage of pedestrians combined with desirable entry curvature. The absolute minimum central island radii generally do not. In addition, the desirable values will generally produce a lower overall crash rate than that produced by the absolute values.
3. The desirable minimum 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 absolute 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 those produced by the absolute values.
4. Minimum central island radius where the design right-turn vehicle is a single unit truck is 7 m.

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 that of 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 Entry Geometry

#### 4.5.1 General

The 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 hence the safety performance of the roundabout. A well-designed roundabout achieves lower relative speeds of vehicles primarily because of 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 limits 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
- decrease in speed required on the circulating carriageway. This minimises single vehicle crashes on the circulating carriageway.
The approach treatment (except for small roundabouts on local roads) should include a raised median 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 to slow drivers.

Section 4 of the Guide to Traffic Management – Part 6: Intersections, Interchanges and Crossings (Austroads 2007) 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.

Where a road authority prefers not to use reverse curves an alternative treatment to assist in the reduction of entry speed may be considered (Section 4.5.3).

### 4.5.2 Single Entry Curve Approach

The minimum acceptable treatment is the provision of a left-hand entry curve on the immediate approach to a roundabout (Figure 4.3). An appropriate entry path radius (Section 4.5.5 and Table 4.2) on the entry curve is essential to encourage drivers to slow down before reaching the roundabout. 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 4.5.5.

Figure 4.3 shows the kerb line of the splitter island placed to be tangential with the central island. Whilst this method has proven satisfactory some road authorities prefer that the prolongation of the splitter island kerb passes 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 authorities cater for this by providing a short horizontal straight between any of the reverse curves (for example, between the entry curve and the circulating carriageway). Alternatively, providing spirals at the ends of each reverse curve may also achieve a satisfactory result.
1. To obtain the length of painted treatment plus the traffic island refer to Table 5.2 of the Guide to Road Design – Part 4A: Unsignalised and Signalised Intersections (Austroads 2009c).

2. Offsets are for illustrative purposes. Refer to Section 10 of the Guide to Road Design – Part 4A: Unsignalised and Signalised Intersections (Austroads 2009c) for guidance on the appropriate offsets for various approach speeds.

Figure 4.3: Typical roundabout entrances with a single-entry curve approach
4.5.3 Reverse Curves on Approaches

Use of reverse curves

The use of a straight approach and a single entry curve will produce an excessive decrease in speed at the start of entry curves in areas of high operating speeds. This can result in the potential for a high single vehicle crash rate on the entry curve. It is important that treatments be applied in these situations to alert drivers and/or more gradually reduce vehicle speeds. One method to achieve this is to provide one or two approach reverse curves prior to the entry curve to limit the maximum decrease in speed between successive horizontal geometric elements to 20 km/h. This treatment is usually required only in areas with high desired speeds (i.e. desired speed ≥ 80 km/h). A detailed example of this treatment compared to a single curve entry is shown in Figure 4.4 and Figure 4.5 respectively.

The design of approaches to roundabouts on rural roads is more critical than for roundabout approaches in urban areas. This is because drivers travelling on rural roads for long distances for long periods of time are less alert. It is therefore especially important to consider the use of speed-reducing devices for approaches on rural roads.

Figure 4.4 shows a roundabout with the eastern approach leg designed as a single entry curve in an area with a high desired speed. The decrease in speed at the start of the entry curve is 41 km/h. The magnitude of this incremental decrease in speed results in a potentially high single vehicle crash rate on the entry curve.

Figure 4.5 shows the same roundabout approach consisting of two reverse approach curves in advance of the entry curve to limit the maximum incremental decrease in speed between successive elements to below the recommended 20 km/h. This geometry will potentially reduce the single vehicle crash rate on the approach.

It is considered that the reverse approach curve treatment:

- should be used in conjunction with reduced speed limits
- works 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.
- is undesirable on downhill approaches (say greater than 3% longitudinal slope)
- should be visible (each approach curve and the central island) to drivers from before the first approach curve. The approach alignment should not disguise the fact that it is an entry to a roundabout
- should desirably be provided with adequate superelevation (of 2.5% to 3%) on each of the curves.

The notations in Figure 4.4 and Figure 4.5 are defined as follows:

<table>
<thead>
<tr>
<th>Notation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SE</td>
<td>Approach speed prior to entry curve/s.</td>
</tr>
<tr>
<td>Rₐ</td>
<td>Radius of the immediate approach curve at entry</td>
</tr>
<tr>
<td>Lₐ</td>
<td>Length of the immediate approach curve at entry</td>
</tr>
<tr>
<td>S</td>
<td>Speed on the immediate approach curve at entry</td>
</tr>
<tr>
<td>ΔS</td>
<td>Speed reduction between an approach curve and the preceding straight or curve</td>
</tr>
<tr>
<td>Rᵥ</td>
<td>Radius of vehicle path on approach curve</td>
</tr>
<tr>
<td>Lᵥ</td>
<td>Length of vehicle path on approach curve</td>
</tr>
</tbody>
</table>
Figure 4.4: Roundabout in a high-speed rural environment – single entry curve

Figure 4.5: Roundabout in a high-speed rural environment – two reverse curves

Superelevation through the reverse curves should be designed in accordance with the Guide to Road Design – Part 3: Geometric Design (Austroads 2009a) and may involve the:
• use of short horizontal straights between each curve (most desirable) to obtain the required superelevation on each curve, to reduce sudden steering movements and to provide more time for drivers to react to each successive curve
• transition of superelevation within reverse circular curves (in constrained situations) where it is not possible to incorporate short horizontal straights.

For more constrained sites at low to intermediate speed approaches, adverse crossfall may have to be adopted on some of the approach curves in accordance with guidance in the Guide to Road Design – Part 3: Geometric Design (Austroads 2009a).

Length of reverse approach curves

The length of each reverse approach 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. Shifting the approach roadway laterally by the width of the traffic lane/s (7 m for the example shown in Figure 4.5) usually meets this criterion.

Alternative treatments to use of reverse curves

Providing successive reverse curves on the approach is one method to mitigate the problems with a large decrease in speed on the entry curve. However, some road authorities may prefer not to use reverse curves generally or at specific sites. Where a single curve entry is adopted and there are concerns about speed reduction on the approach, the following treatments may be considered to encourage drivers to enter at an appropriate speed:

• long median islands and 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 to create 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 (including the provision of reverse curves) is unknown.

4.5.4 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 4.16).
4.5.5 **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 desirable values given in the table should be used whenever possible as they will generally produce lower overall crash rates than those produced by the absolute values. 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 with 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**

<table>
<thead>
<tr>
<th>Desired driver speed on the leg prior to the roundabout (km/h)</th>
<th>Maximum entry path radius (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single-lane entries¹</td>
</tr>
<tr>
<td></td>
<td>Desirable</td>
</tr>
<tr>
<td>≤ 40</td>
<td>55</td>
</tr>
<tr>
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<tr>
<td>80</td>
<td>55</td>
</tr>
<tr>
<td>≥ 90</td>
<td>55</td>
</tr>
</tbody>
</table>

¹. Construction of the entry path of a single-lane entry for roundabouts comprising one or two circulating lanes is given in Figure 4.6.
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 4.7.
³. Construction of the entry path of a two-lane entry – cutting across lanes for a two-lane roundabout is given in Figure 4.8.
⁴. Radius of the entry path for drivers staying in the correct lane as determined in Figure 4.7.

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 (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 the roundabout safety parameters listed in Arndt (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 4.6. 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 ‘M1’.

Step 2 – Draw a curved line parallel to the edge of the central island at an offset ‘M2’. 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.

Source: Queensland Department of Transport and Main Roads ([date]).

Figure 4.6: Construction of the entry path of a single-lane entry

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 4.7. 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 ‘M1’.

Step 2 – Draw a curved line parallel to the edge of the central island at an offset ‘M2’. 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 criterion in Step 4, appropriate entry curvature has not been provided.

Source: Queensland Department of Transport and Main Roads ([date]).

Figure 4.7: Construction of the entry path of a two-lane entry – staying in the correct lane
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 4.8. 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 ‘M1’.

- **Step 2** – Draw a curved line parallel to the edge of the central island at an offset ‘M2’. 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 4.7 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 criterion in Step 4, appropriate entry curvature has not been provided.
4.5.6 **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.
Splitter island kerbing should be light coloured or painted white. 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 there is a need 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 m²). However, where space is constrained at local street roundabouts a minimum area of 8 m² to 10 m² may be provided.

For roundabout approaches on local roads that carry a relatively low volume of traffic the general minimum area of kerbed splitter island should be 5 m² to 8 m².

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.

Preferably the splitter island and its approach pavement markings should 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 the Guide to Road Design – Part 4A: Unsignalised and Signalised Intersections (Austroads 2009c)). For example, in a 100 km/h environment an overall length of 155 m would be required resulting in a splitter island about 50 m to 60 m long.

The lateral restriction and funnelling provided by the splitter island encourages speed reduction as vehicles approach the entry point. 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 drivers’ 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 Section 5 of the Guide to Road Design – Part 4: Intersections and Crossings – General (Austroads 2009b). 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 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 to allow the use of a smaller width of circulating carriageway.

Because travel through roundabouts involves complex reverse-turn movements, particular care is needed in the use of simple turning path templates (Section 5, Guide to Road Design – Part 4: Intersections and Crossings – General (Austroads 2009b)) 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 kerb should be provided. Initial selection of circulating carriageway widths 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

<table>
<thead>
<tr>
<th>Central island radius(^1) (m)</th>
<th>Width required for design vehicles(^2) (m)</th>
<th>12.5 m single unit truck</th>
<th>19 m semi-trailer</th>
<th>25 m B-double</th>
<th>Type 1 road train</th>
<th>Type 2 road train</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>-</td>
<td>-</td>
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<td>-</td>
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<td>5.7</td>
</tr>
</tbody>
</table>

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.

**Dual lane roundabouts**

The circulating carriageway width of dual 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.

Initial selection of circulating carriageway widths 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 a computer software package (Section 5, *Guide to Road Design – Part 4: Intersections and Crossings – General* (Austroads 2009b)).
Table 4.4: Initial selection of two-lane roundabout circulating carriageway widths

<table>
<thead>
<tr>
<th>Central island radius (m)</th>
<th>12.5 m single unit truck</th>
<th>19 m semi-trailer</th>
<th>25 m B-double Type 1 road train</th>
<th>Type 1 road train</th>
<th>Type 2 road train</th>
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</table>

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 body text.

There are cases in 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 4.12.

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 4.9.

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, except for freight routes or roads serving sea ports, for example. For the roundabout in Figure 4.9, 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 $R_1$ from the initial layout. The determination of $R_1$ 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 $R_1$ can then be used to verify that dimension ‘$W$’ is adequate.

It can be seen from Figure 4.9 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 $W$. Whilst 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 4.10). Where it is required to narrow the circulating carriageway to control the speed of smaller vehicles (e.g. passenger cars), it may be necessary to accommodate buses by the use of encroachment areas (Section 4.6.3 and Figure 4.12). 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 kerb 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), in case the front over-hang 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.

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, for example, 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 (Section 5.3, Guide to Road Design – Part 4: Intersections and Crossings – General (Austroads 2009b)).

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 the size of these vehicles 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.

It is desirable that all roundabouts on bus routes are 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 4.10 and Figure 4.11 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 4.12 illustrates encroachment areas that may be provided to cater for a checking vehicle or an over-dimensional vehicle that is turning right and left at a roundabout.

All roundabouts should have road lighting (refer to Section 7.1) 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.
1. Alternative profiles that discourage drivers of passenger cars from mounting the raised area, which 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 the reinforced concrete pavement to prevent differential movement. Dimensions shown are examples only.

6. Clearance is measured to the swept path of vehicle, not to the wheel path.

Figure 4.12: Typical encroachment area detail at a roundabout
4.7 Exit Curves

The exiting/circulating vehicle crash rate at any particular exit point of multi-lane 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 or curves 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).

In areas where a significant number of pedestrians cross 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 exiting traffic should be slowed 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 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 4.12.

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 necessary 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 4.13 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 they result 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.
**Figure 4.13:** Examples showing desirable and undesirable separation between roundabout legs

Source: QDMR (2006)
4.10 Superelevation, Gradient and Drainage

4.10.1 Crossfalls

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. A further advantage of adverse crossfall is 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. It 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 movements 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 which 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 (i.e. between 10 m 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 which 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 multi-lane 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](image-url)
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%. Whilst 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
- 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 Guide to Road Design – Part 5: Drainage Design (Austroads 2008b).
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 with 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 4.15 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 orient the oval to favour a predominant right-turning movement or to assist a substantial right-turning movement of heavy vehicles.
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, and semi-mountable kerbs is shown in Figure 4.16.

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 4.16: Roundabout at T-intersections in an urban area](image)
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 2006 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. In such cases traffic signals are preferred to assist pedestrians to cross the road safely.

A number of studies have shown that roundabouts increase the risk of crashes for cyclists and this fact 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.


5.2 Pedestrians

 Whilst 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.

Vision-impaired people rely on vehicle noise to obtain cues of whether it is safe to step onto the road. Roundabouts can be especially problematic for vision-impaired people 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 ramps further down the approaches where vehicles only approach from two directions.

Pedestrian kerb ramps are provided at roundabouts 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. Design features that could be expected to improve the level of service and safety for pedestrians at roundabouts 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
- prohibition of parking on approaches to provide clear visibility
- pram crossings that are designed for persons who have a disability
- street lighting
- signs and vegetation located so as not to obscure ‘smaller’ pedestrians
- conformance to the Australian Commonwealth Disability and Discrimination Act (1992) or the equivalent New Zealand Act as appropriate, and also AS 1428:2003 and NZS 4121:2001
- provision of pedestrian crossings on approaches (zebra or signalised).
It is important that:

- pedestrians are 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 law
- crossings are located with reference to pedestrian desire lines
- kerb ramps and storage areas in splitter islands are adequate to accommodate the pedestrian demand
- kerb ramps and crossings are oriented to allow pedestrians to travel in a straight line across the road by the shortest route
- uncontrolled crossings are located generally about one to two car lengths (6 m to 12 m) back from the holding line so that vehicles can select gaps without having to be distracted by pedestrians and pedestrians can move between cars
- at low-speed sites (e.g. town centre or shopping precinct) pedestrian (zebra) crossings may be provided at the holding lines. However, this decreases the rate at which vehicles can both enter and leave the roundabout and this must be analysed (Guide to Traffic Management – Part 3: Traffic Studies and Analysis (Austroads 2009h)).

Where a significant volume of pedestrians crosses all approaches and departures at a site, practitioners should question whether a roundabout is the appropriate treatment and consider alternatives such as a signalised intersection.

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 m to 24 m preferred). Refer also to Section 4.5.3 and Figure 4.9 of the Guide to Traffic Management – Part 6: Intersections, Interchanges and Crossings (Austroads 2007)
- 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 oriented so that pedestrians are required to face oncoming traffic as they approach the pedestrian detector buttons.

It is emphasised that with most roundabouts, special crossing facilities will not be necessary. Generally, the installation of well-designed splitter islands of sufficient size to hold and protect pedestrians allows them to cross only one direction of traffic at a time. This should result in pedestrians being able to move more safely and freely around the intersection than was the case before the installation of the roundabout. On small roundabouts in local streets, a cut-through of splitter islands at pavement level or a painted island may be appropriate.

However, where pedestrian volumes are high, serious consideration should be given to the use of an alternative intersection treatment. This is especially true where the pedestrian content consists of school children or the elderly.

Further information regarding the design of pedestrian facilities, including crossings and kerb ramps is provided in Section 8 of the Guide to Road Design – Part 4: Intersections and Crossings – General (Austroads 2009b).
5.3 Cyclists

5.3.1 Introduction

Designers should strive to design roundabouts to provide an acceptable level of safety for cyclists. Section 4.5.2 of the Guide to Traffic Management – Part 6: Intersections, Interchanges and Crossings (Austroads 2007) describes the different types of cyclists that need to be catered for at roundabouts and traffic management considerations.

The extent to which special geometric treatments and/or traffic control measures are needed to achieve an adequate level of safety for cyclists will depend on:

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

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 accident rates at roundabouts and should also minimise entering/circulating vehicle crashes involving cyclists. Therefore, the design concepts given in this guide to minimise entry speeds should also minimise accidents involving cyclists.

The benefit of the treatments suggested in this section to improve the situation for cyclists at roundabouts has not necessarily been confirmed through appropriate studies. However, in the absence of such information they are generally considered to provide an advantage in that they allocate space to cyclists and/or raise motorists’ awareness that cyclists may be present on the road.

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. However, on designated bicycle routes that cater for commuter cyclists consideration should be given to the provision of signalised intersections instead of a roundabout.

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.

At larger single-lane or multi-lane roundabouts where speeds are higher, consideration should be given to treatments that assist young or inexperienced cyclists as well as commuter cyclists, namely:

- 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
- an on-road bicycle lane to improve drivers’ awareness of the possible presence of cyclists and to provide some separation for cyclists from motor vehicles within the roundabout.

However, the extent to which special geometric treatments and/or traffic control measures are needed will depend on:

- the daily vehicle traffic volume and the peak-hour flows
- the proportion of cyclists in the total traffic stream
- the functional classification of the roads involved
- the overall traffic management strategies for the location.
5.3.2  Local Roads – No Bicycle Facility

Local roads provide access for cyclists across the road network. They typically comprise roads that have low traffic speeds (< 50 km/h) and relatively low volumes (< 3000 vpd). These traffic conditions generally enable cyclists to safely share the road with other traffic.

Figure 5.1 shows an example of a low-volume single-lane roundabout which is based on cyclists occupying the approach lane. The approach lane width should not exceed 3.0 m as wider lanes may encourage risky overtaking behaviour by motorists.

![Figure 5.1: Bicycle route through a single-lane roundabout – no bicycle facility](image)

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 $W_e$ is 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 RTA (2005)

5.3.3  Bicycle Lanes at Single-lane Roundabouts

Local street with bicycle lanes

Figure 5.2 shows a treatment that is suitable for bicycle routes at local street intersections that have low approach speeds and low volumes. It provides warning signs and bicycle lanes on the approaches but no special treatment within the circulating roadway. The bicycle lanes must extend to the holding lines so that a squeeze point for cyclists is not created. The low volume of heavy vehicles on this type of road means that the road can be shared with cyclists. Cyclists typically turn right with general traffic.
Figure 5.2: Bicycle lane at a small single-lane roundabout on a local road

Source: Adapted from RTA (2005)
Collector road or arterial road with physical separation of bicycle lanes

Where bicycle routes pass through single-lane roundabouts that have relatively high traffic volumes and moderate speeds, a marked bicycle lane may be provided within the roundabout as shown in Figure 5.3. The circulating bicycle lane should have a contrasting surface that provides cyclists with separate space and comfort but no special priority. However, advance warning signs, a contrasting surface and bicycle pavement logos should be provided to ensure that the facility is highly visible and warns motorists of the likely presence of cyclists. Cyclists passing straight through the roundabout or turning left will remain in the bicycle lane. Cyclists may turn right with general traffic or undertake a hook turn from the left side of the exit. As the islands separating cyclists from motor vehicles are narrow in this treatment it is most important that they are provided with a high standard of delineation (e.g. narrow retro-reflective signs on all noses facing traffic approaching the roundabout and departing from the roundabout).

Notes:
- BD = 1.5 m; BA = 1.25 m; VA = entry width to suit design vehicle; VD = exit width to suit design vehicle.
- Holding line to extend across entire entry including bicycle lane.
- Source: Adapted from RTA (2005)

Figure 5.3: Two bicycle routes crossing at a single-lane roundabout with physically separated bicycle lanes
Collector road or arterial road with no physical separation of bicycle lanes

The treatment shown in Figure 5.4 has been adopted and implemented by some road authorities. It provides a bicycle lane on the roundabout approaches and departures without any physical separation. It is known that many motorists will cut across the bicycle lane on the entry and exit curves when no cyclists are present. For this reason, the maximum entry path radius criteria in Section 4.5.5 should be applied by assuming drivers will cut across the bicycle lane (i.e. Step 3 in Figure 4.6 will involve drawing a line 1.5 m from the kerbed left edge of the bicycle lane).

There is some concern that this treatment may lead to conflict between heavy vehicles and bicycles where the route carries a relatively high volume of both freight vehicles and cyclists. It is therefore suggested that the entries of these treatments should be designed so that the swept paths of entering design vehicles do not have to encroach into the bicycle lane. However, where a site has low volumes of both trucks and bicycles, encroachment may be allowed if necessary to achieve the maximum entry radius criteria in Section 4.5.5.

5.3.4 Multi-lane Roundabouts on Arterial Roads

Multi-lane roundabouts usually carry high traffic volumes and have higher entry speeds than local street roundabouts and therefore create safety problems for cyclists. It is anticipated that only experienced cyclists will use this type of roundabout and whilst they may feel reasonably comfortable in selecting a gap and turning left and travelling straight through a multi-lane roundabout in the bicycle lane, 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.

There is currently no treatment that would assist cyclists to turn right safely through a multi-lane roundabout. However, the provision of bicycle lanes within multi-lane arterial road roundabouts is considered to offer some advantages to cyclists in that these lanes:
• heighten the awareness of motorists approaching the roundabout that cyclists may be present
• provide designated space on the circulating carriageway and thereby assist experienced cyclists to negotiate the through movement
• assist cyclists to undertake a hook turn (right turn) as described in the Australian Road Rules (NTC 2008).

Some jurisdictions may prefer not to provide the islands between the bicycle lane and the adjacent traffic lanes at multi-lane roundabouts. Under this arrangement, the criteria given in Section 5.3.3 for single-lane roundabouts with no physical separation between cyclists and motorists also apply.

Where a multi-lane roundabout carries high volumes of both heavy vehicles and bicycles it is recommended that the bicycle lane should be physically separated from the general traffic lanes on the approaches as illustrated in Figure 5.5. Designers should design the island in accordance with the normal design principles for traffic islands (Section 10, Guide to Road Design – Part 4: Intersections and Crossings – General (Austroads 2009b)). Figure 5.6 shows suggested details of the separation island which is similar in principle to a pedestrian and cyclist refuge island.
Figure 5.5: Bicycle lanes at a two-lane roundabout with physical separation for cyclists
Figure 5.6: Details of an island on a multi-lane roundabout entry to separate cyclists and motorists

Figure 5.7: Details of an island on a multi-lane roundabout exit to separate cyclists and motorists
5.3.5 Bicycle Paths and Shared Paths at Roundabouts

Bicycle paths or shared paths may be provided adjacent to roundabouts to provide safe passage for inexperienced cyclists and pedestrians. At sites where there is a relatively small volume of pedestrians and cyclists the treatment in Figure 5.8 with normal kerb ramps will suffice.

Where a shared path is provided at a multi-lane roundabout and bicycle lanes exist on the approach, the crossing treatment shown in Figure 5.9 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 is also possible to modify this treatment so that the bicycle lane passes through the roundabout, thereby providing an option for cyclists to remain on the road or to utilise the shared path and road crossings. The treatment in Figure 5.9 also suggests that cyclists using the shared path crossings should be controlled by give way signs.
5.3.6 Other Considerations

Other situations where special consideration of cyclists is required to assist access and safety include:

- a path to provide a bypass of three-legged roundabouts for cyclists travelling straight through the intersection (Figure 5.10)
- where a left-turn slip lane is provided on the corner of a roundabout (Figure 5.11).

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.
Notes:
Smooth ramps provided for cyclists to move from the bicycle lane to the path and return to the bicycle lane.
Path provides a safer treatment across the top of the roundabout.

Figure 5.10: Roundabout at a T-intersection – path connecting bicycle lanes

Figure 5.11: Bicycle lane continuing past a left-turn slip lane at a roundabout
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 (Transit NZ 2007 and Transit NZ 2008) and the Guidelines for Marking Multi-lane Roundabouts (LTNZ 2005).

Practitioners in Australia and New Zealand should use the signs contained 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>
<thead>
<tr>
<th>Table 6.1: Some considerations in regard to signs and pavement markings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Traffic control device</strong></td>
</tr>
<tr>
<td>---------------------------</td>
</tr>
<tr>
<td>Pavement markings</td>
</tr>
<tr>
<td>The holding line should be painted parallel to the circulating roadway, particularly at multi-lane approaches so that the drivers in the left lane can see past adjacent vehicles on their right.</td>
</tr>
<tr>
<td>An edge line or continuity line should not be painted across the exit.</td>
</tr>
<tr>
<td>In general, lane direction arrows are not necessary on the approaches to single-lane roundabouts.</td>
</tr>
<tr>
<td>Lane direction arrows should be provided where there is more than one lane on an approach.</td>
</tr>
<tr>
<td>Raised retro-reflective pavement markers may be used on lane lines to improve delineation at night.</td>
</tr>
<tr>
<td>Pavement markings may be in paint. However, long life materials (particularly in the circulating roadway of multi-lane roundabouts) should be considered to reduce the frequency of maintenance and ensure that good lane delineation is provided in critical areas.</td>
</tr>
<tr>
<td>All pavement markings on approaches should desirably be visible for approaching drivers over the full length of approach sight distance.</td>
</tr>
<tr>
<td>Regulatory signs</td>
</tr>
<tr>
<td>Place as near as practicable to the holding lines.</td>
</tr>
<tr>
<td>Locate in the most prominent location (usually on the raised splitter island).</td>
</tr>
<tr>
<td>Provided on both sides of multi-lane entries.</td>
</tr>
<tr>
<td>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.</td>
</tr>
<tr>
<td>Warning signs</td>
</tr>
<tr>
<td>Are generally necessary where the presence of a roundabout may be unexpected.</td>
</tr>
<tr>
<td>May be used where a diagrammatic advance direction sign is not provided.</td>
</tr>
<tr>
<td>Should be considered where approach speeds are high or approach sight distance is restricted.</td>
</tr>
<tr>
<td>Hazard markers</td>
</tr>
<tr>
<td>Place on central island opposite splitter island.</td>
</tr>
<tr>
<td>Desirable on large splitter islands in high-speed areas to emphasise the curved approach.</td>
</tr>
<tr>
<td>Advance direction signs</td>
</tr>
<tr>
<td>Should be provided on all approaches to roundabouts in rural areas and where practicable on all major urban arterial roads.</td>
</tr>
<tr>
<td>Large diagrammatic signs are preferred on high-speed rural and urban arterial roads.</td>
</tr>
<tr>
<td>Intersection direction signs</td>
</tr>
<tr>
<td>Are to be placed on the left-hand side of the circulating roadway at each exit.</td>
</tr>
<tr>
<td>May be placed on the splitter island at an exit provided that sight distance is not restricted for entering traffic.</td>
</tr>
<tr>
<td>Mount at a height that does not impede either car or truck drivers’ lines of sight.</td>
</tr>
</tbody>
</table>
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.

Source: Based on AS 1742. Signs shown for one approach only; provide on all approaches.

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

6.3 Multi-lane Arterial Road Roundabout

Figure 6.2 shows an example of signs and markings at a multi-lane roundabout. The roundabout regulatory signs, holding lines, pavement arrows on approaches, and exit lines are critical to the successful and safe operation of a multi-lane roundabout. Reference should be made to AS 1742.2 in Australia, and in New Zealand to MOTSAM (Transit NZ 2008) and the Guidelines for Marking Multi-lane Roundabouts (LTNZ 2005).
Figure 6.2: An example of signs and markings at a multi-lane arterial road roundabout

In special circumstances some jurisdictions prefer to provide a spiral marking at multi-lane roundabouts. However, other jurisdictions do not favour spiral markings for use at new roundabouts or at all, and therefore jurisdictional guidelines should be consulted. A discussion on the use of spiral markings and the reasons why some jurisdictions do not favour them is provided in Appendix D.
7 ROADWAY LIGHTING AT ROUNDABOUTS

7.1 Introduction
The general principles and guidance on lighting of traffic routes are covered in the Guide to Road Design – Part 6B: Roadside Environment (Austroads 2009g) and in AS/NZS 1158: 2007.

The satisfactory operation of a roundabout relies on the ability of drivers to enter into and separate safely from a circulating traffic stream. To do this a driver must be able to perceive the general layout of the intersection, the traffic entering the roundabout from the approach immediately to the right, and traffic approaching traffic on the circulating roadway, in sufficient time to act in an appropriate manner. This task is particularly demanding at night and for this reason lighting should be provided on all roundabouts on all classes of roads.

7.2 Lighting Considerations at Roundabouts
Practitioners should refer to the Guide to Road Design – Part 6B: Roadside Environment (Austroads 2009g) and AS/NZS 1158:2007; however, the following principles and desirable features are relevant to lighting of roundabouts:

- Lights should be located so that they provide good illumination on the approach nose of the splitter islands, the conflict area where traffic enters the circulating stream, and at places where traffic streams separate at points of exit.
- Specific attention should be given to the lighting of the pedestrian and cyclist crossing areas, particularly at sites where pedestrian/vehicle conflict is likely to be significant at night.

The risk of an errant vehicle colliding with a pole should always be considered when designing a lighting system and the use of impact absorbing poles is recommended. At roundabouts, lighting columns and other poles should not be placed or retained in vulnerable areas such as:

- within small splitter islands
- within large splitter islands directly in line with approaching traffic
- on the central island directly opposite the entries
- on the left-hand side of exits (rigid poles) as these areas have a high risk with respect to run-off-road crashes.

7.3 Typical Road Lighting Schemes at Roundabouts
Figure 7.1 and Figure 7.2 show typical lighting arrangements for roundabouts on arterial roads for different sized roundabouts. Where the central island is large and the circulating roadway is wide it may be advantageous to light the circulating carriageway and entry/exit roadways from a single intermediate height (12 m to 18 m) or high mast lighting column located in or near the middle of the central island (Figure 7.1). Additional conventional height lights near the approach noses at splitter islands will generally also be necessary.

In other instances, and particularly where the central island is large and the circulating carriageway narrow, it may be more appropriate to light from conventional height poles around the outer perimeter of the roundabout (Figure 7.2). This is particularly suited to locations where existing power distribution poles can be used for lighting purposes. However, it is important that these poles are located clear of vulnerable areas.
Lighting of roundabouts on arterial roads should be designed to suit individual site considerations and computations should be undertaken by an experienced road lighting design practitioner to verify that the intersection is lit to an appropriate level and uniformity as required under AS/NZS 1158.

Figure 7.1: Typical lighting arrangement at an arterial road roundabout

Figure 7.2: Alternative typical lighting arrangement at an arterial road roundabout
Lighting of roundabouts in local streets (including collector roads) is generally simple because of their small size and the lower level of lighting that is generally applicable to these areas. In some cases it may be appropriate to light the intersection from one or two lanterns bracketed from existing power poles, but consideration should be given to relocating these poles from vulnerable areas (Figure 7.3). Lighting at local street roundabouts should also comply with AS/NZS 1158. It would generally be undesirable to place the poles in the central island because of their small size and, for aesthetic and environmental reasons, high mounting heights and high wattage lights would also be inappropriate.

Figure 7.3: Typical lighting arrangement at a local street roundabout
8 LANDSCAPING AND STREET FURNITURE

8.1 Introduction

Guidelines relating to landscaping generally within road reservations are provided in the *Guide to Road Design – Part 6B: Roadside Environment* (Austroads 2009g). 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
- not obscure the view to potentially conflicting vehicles for a driver at the holding line of a roundabout.

On the other hand, 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.

8.2 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 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 is the case with wide medians, they should not be used to accommodate anything (e.g. trees, planter boxes, or 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 desire to 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 can be provided in the central island, whether it is raised or depressed, including large trees. Figure 8.1 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 8.1: Example of a landscape treatment in the central island of a large roundabout](image)

Note: Large tree and artwork in the centre are set well back from kerb. Grass and low height groundcover 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 given 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.

8.3 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.

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 (e.g. 150 mm to 200 mm diameter) located centrally on 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 are not impeded. Examples are provided in Figure 8.2 and Figure 8.3.
8.4 Maintenance

The desire to establish vegetation needs to be considered 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 account of these issues.

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.
9 REFERENCES


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**Australian and New Zealand standards**


AS 1428.1 – 2001, *Design for access and mobility part 1: general requirements for access – new building work*.

APPENDIX A  CRASH TYPES

A.1  Australia

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

![Diagram of a typical roundabout and typical crash types](image)

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

Source: QDMR (2006)

Figure A 1: Geometric elements of a typical roundabout and typical crash types
Figure A 2: Crash categories

Source: QDMR (2006)
A.2 New Zealand

Research has been undertaken to develop accident models for roundabouts in New Zealand (Turner et al. 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.

Source: Turner et al. (2006)

Figure A 3: Road user involvement in injury accidents at urban roundabouts
Figure A 4: Injury accident types of reported crashes at urban roundabouts
APPENDIX B  ROUNDBOOTH STUDY AND PROGRAM

Arndt (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 between entering and circulating vehicles of 50 km/h 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 multi-lane roundabout leading to higher sideswipe vehicle crashes). This criterion is for multi-lane roundabouts only and will minimise side swipe vehicle crashes on the entry curve.
- A maximum relative speed between exiting and circulating vehicles of 35 km/h to minimise crashes between these vehicle streams. This criterion is for multi-lane 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 his 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 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 (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 (Section 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 the relative speed of entering vehicles and will considerably lower the multiple vehicle crash rate between entering and circulating vehicles.

Figure C 1: Single-lane urban roundabout showing relative speed – adjacent approaches with minimal entry curvature
C.2 Examples of Improved Roundabout Entries

C.2.1 Introduction

Figure C 3, Figure C 4 and Figure C 5 show examples of roundabouts with poor entries and recommended designs that provide acceptable geometry.
C.2.2 Example 1

Figure C 3: Example 1 – design modifications to improve geometry
C.2.3 Example 2

Figure C 4: Example 2 – design modifications to improve geometry
C.2.4 Example 3

Figure C 5: Example 3 – design modifications to improve geometry
APPENDIX D LINEMARKING OF MULTI-LANE ROUNDABOUTS

D.1 Introduction

The convention for linemarking at multi-lane roundabouts is to provide exit markings that guide circulating traffic out through the exit in lanes as shown in Figure D 1 (although 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 the use of them is limited by some road authorities.

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: LTNZ (2005)

Figure D 1: An example of a spiral marking scheme within a multi-lane urban arterial roundabout
Linemarking of multi-lane 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 multi-lane 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 less 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 multi-lane 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 multi-lane roundabouts with some or all legs aligned at angles substantially more or less than 90°
D.2 Single-lane Exits Adjacent to Two Circulating Lanes

For multi-lane 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 line marking 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, multi-lane 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 line marking 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 from 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 linemarkings (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 spiral 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. Desirably, new roundabouts should 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, and advice should be sought from the relevant jurisdiction.
Figure D 4: Examples showing potential conflicts arising without the spiral line marking system
Figure D 5: Examples showing the use of the spiral line marking system for the examples shown in Figure D 4

Desirably the geometry in these examples should not be used for the design of new roundabouts. These examples show the use of "spiral" linemarking which is required to help guide motorists onto single lane exits adjacent to two circulating lanes. "Spirals" are generally only suitable for retrofitting to existing roundabouts.
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. The basic at-grade intersections (cross and T types) will generally record significantly higher multiple vehicle crash rates than the roundabout.

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 crashes. Their 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° angle. The desired speed on each of the crossroads 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 crossroads. 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 the crossroads 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° angle
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 feel less safe at roundabouts, particularly at exits. This is because, unlike traffic signals, roundabouts do not give priority to pedestrians over through traffic.

An internal VicRoads report (Tumber 1997), studied pedestrian accidents at roundabouts constructed on arterial roads within the Melbourne metropolitan area from 1987 to 1994. Over that period 64 crashes involving pedestrians were identified at 38 roundabouts. The study concluded that the average yearly pedestrian crash rate per roundabout was at a low level and that the severity of crashes was also relatively low. The study also reported that:

- a large proportion of roundabouts where pedestrians were involved in crashes were located in shopping precincts
- the temporal pattern of crashes thus reflected periods of higher pedestrian use (lunchtimes, late afternoon, weekdays, school and other holiday periods)
- pedestrians aged 70 years and over had a slightly higher involvement rate than the average for all crashes
- 45% of pedestrians were hit in the zone where vehicles were approaching the roundabout, 17% at the exit, and a further 17% were hit whilst crossing the circulating roadway.

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 cross 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 (1997), 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. Therefore, the design concepts in this guide will 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. Separate cycle paths have been found to be safer than a bicycle lane within the circulating roadway, particularly at highly trafficked roundabouts. This treatment 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, multi-lane 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.
COMMENTARY 2

Practitioners are referred to Arndt (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 so that crash rates are minimised. 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.
COMMENTARY 3

The circulating carriageway of a roundabout does not have to provide a consistent number of lanes throughout. It 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: Multi-lane roundabout permanently constructed with reduction to one lane on the circulating carriageway](image-url)
Figure C3 2: Multi-lane roundabout showing interim reduction to one lane in the circulating carriageway

Source: Based on LTNZ (2005)