International comparison of roundabout design guidelines

by Janet Kennedy

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by Janet Kennedy (TRL Limited)

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Client:	**Highways Agency (Ian Sandle)**

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CONTENTS

Executive summary

Background

Roundabouts have been a key form of junction in the UK for many years. They are used on all classes of road in both urban and rural areas for the efficient and safe control of traffic, particularly where side road flows are high. Roundabouts are the most common type of control used at motorway intersections, and are heavily used throughout the UK's trunk and principal road network, as well as on local authority roads.

The UK Geometric Design Standard for Roundabouts at the time of this review (TD 16/93) is based on extensive research which led to predictive relationships incorporating the critical variables found to influence safety and capacity. Entry width and sharpness of ‘flare’ were established as the primary determinants of capacity/delay whilst a combination of entry deflection and entry width was their equivalent for safety. However, it was recognised that although roundabouts performed well in terms of overall safety, the involvement in accidents of pedal cyclists and motor cyclists at this junction type was relatively high. More recently, concerns about pedestrians and equestrians, and the prevention of large goods vehicle roll-over accidents at roundabouts have become issues.

The main objective of the report is to provide a comprehensive review of international roundabout design that will lead to a revised Design Standard to meet the needs of modern roads. Mini-roundabouts are to be part of a separate UK standard, but a comparison of the key design elements is included for consistency.

Review

Where possible, the review is based on the guidelines or standards for the country concerned that were in current use in early 2004. In a few cases, a conference paper on the main design elements has been used, because of difficulty in obtaining the standard and to avoid the need for translation. It is not known to what extent the standards or guidelines are adhered to.

Compared with TD 16/93, the roundabout designs in the guidelines in Germany, France and the Netherlands are notably smaller and have tighter geometry which leads to lower circulating speeds. This generally smaller design is reflected in the fact that in those countries, roundabouts are mainly used for reasons of road safety. In line with this, design features that are used to increase capacity on UK roundabouts (e.g. flared entries and segregated left turn lanes) are not recommended in Germany, France and the Netherlands, because they tend to lead to higher circulating speeds.

Single lane roundabouts are generally preferred over double lane roundabouts on safety grounds (the French guidelines do not even provide recommendations for urban double lane roundabouts and the German guidelines on urban double lane roundabouts are considerably less detailed and prescriptive than the single lane ones).

Australian guidelines appear to be more comparable with the UK standard, probably because of the greater emphasis given to capacity than in continental Europe.

The American guidelines provide a range of different types of roundabouts, in which higher capacity designs (for use on arterials) are more comparable with the UK and Australian design standards and compact designs (for use on local urban roads) show more similarity to the German, French and Dutch designs.

The amount of information traced on Swedish, Danish and Norwegian guidelines was relatively limited, but showed designs that are generally larger than those in Germany, France and the Netherlands.

Detailed information on the design of cyclist provision is given in German, French and Dutch guidelines. A more limited description of cycle provision is given in the Danish, Australian, UK and American guidelines.

A notable difference is that all of the overseas guidelines studied recommend outward crossfall on roundabouts, whereas, with the exception of mini-roundabouts, inward crossfall is recommended in TD 16/93.

Conclusions

The conclusions were as follows:

- The inscribed circle diameter should not be unnecessarily large. In particular, if the roundabout is at-grade, the inscribed circle diameter should not exceed 100m.
- A truck apron (overrun area i.e. raised low-profile area around a central island) should continue to be used at small roundabouts if there is sufficient land-take to use a solid island roundabout rather than a mini-roundabout. The edge profile of a truck apron in TD 16/93 is allowed to be up to 50mm. In order to be consistent with the Traffic Calming Regulations, the vertical face should not exceed 15mm. The apron should be capable of being mounted by the trailer of a large goods vehicle, but be unattractive to cars e.g. by having a slope and/or textured surface.
- Outward crossfall should be permitted on smaller roundabouts in urban areas.
- Lane widths at entry should remain at 3m to 3.5m at multilane entries, but at single lane entries, the width should be 4.5m.
- Adding an extra lane at roundabout entries should require justification rather than being automatic. The recommended effective flare lengths of 5m (urban) and 25m (rural) should remain.
- Suitable values for the entry (kerb) radius are 20m at larger roundabouts, 10-15m at smaller roundabouts.
- Suitable values for the exit (kerb) radius are 20-100m at larger roundabouts, 15-20m at smaller roundabouts.
- Suitable values for the entry angle are 20 to 60 degrees, particularly at smaller roundabouts.
- Flaring should continue to be used in preference to a segregated left turn lane as this requires less land take and is safer for non-motorised road users.
- The entry path radius on any approach should not exceed 100m. It should not exceed 70m at small urban roundabouts.

Cycle lanes should not be used on the circulatory carriageway. Cyclists should mix with traffic at urban roundabouts with low flow. External cycle paths that do not form part of the circulatory carriageway are the best facility at larger urban roundabouts.

Where vehicle flow is low, an informal crossing (a dropped kerb) is generally adequate for pedestrians. At medium flows, where there is a substantial pedestrian demand, a formal crossing should be provided close to the roundabout (but upstream of any flaring). Where a signal controlled pedestrian or cycle crossing is provided, it should be either at 20m or at least 50m from the give way line to avoid confusion with the roundabout itself and to minimize queueing back onto the circulatory carriageway.

On dual carriageway roads, or single carriageway roads with a long splitter island, visibility to the right may be limited by use of planting or other screening (at least 2m high) until vehicles are within 15m of the give way line, to reduce excessive entry speeds.

The possibility of rollover of large vehicles should be minimized by keeping approach speeds low and ensuring that roundabouts have no abrupt changes in geometry.

Recommendations

There is scope for introducing in the UK Standard a new “compact” roundabout with single lane entries, exits and circulatory carriageway. This style of roundabout would be most appropriate on low flow roads. In urban areas, the design would incorporate tighter geometry and outward crossfall, in order to slow traffic; these could have substantial numbers of pedestrians or cyclists. This compact roundabout would form part of a design hierarchy to depend on road type, whether the speed limits on the approach roads exceed 40mph and on the levels of vehicle and non-motorised user flow. If required, pedestrian provision would comprise Zebra crossings at 5m from the give way line. No special provision for cyclists would be necessary.

New design hierarchy

The types of roundabout are Signalised, Grade Separated, Dual Carriageway (one or more approaches is dual carriageway), Normal (all approaches are single carriageway and design broadly follows TD 16/93), Compact (“continental style”, with single lane entry, exit and circulatory carriageway) and Mini Roundabout.

The various factors for the design hierarchy are as follows:

- Speed limit within 100m of give way line (>40mph, ≤40mph)
- Single or dual-carriageway
- Level of vehicle flow
- Level of cyclist flow
- Level of pedestrian flow

At a roundabout with one or more dual carriageway arms, or a busy single carriageway roundabout, the design should be similar to that in TD 16/93. If there is a non-motorised user need, it should be catered for by use of a signalised crossing (Puffin, Toucan or Equestrian as appropriate). In circumstances where there is a need for a signalised crossing on more than one arm, a signalised roundabout may be preferable.

At a single carriageway roundabout with medium flow, the design will again be similar to that in TD 16/93. If warranted, either a signal controlled or a Zebra crossing should be used, depending on the speed limit and the level of flow.

Where total inflow is below 8,000 vehicles per day, cycle facilities are not necessary, but on some occasions, a pedestrian crossing (a Zebra or possibly a signal controlled crossing) should be provided.

1 Introduction

1.1 Background

Roundabouts have been a key form of junction in the UK for many years. They are used on all classes of road in both urban and rural areas for the efficient and safe control of traffic, particularly where side road flows are high. Roundabouts are the most common type of control used at motorway intersections, and are heavily used throughout the UK's trunk and principal road network, as well as on local authority roads.

The current UK Geometric Design Standard for Roundabouts TD 16/93 (DMRB 6.3.2) is based on extensive research which led to predictive relationships incorporating the critical variables found to influence safety and capacity. Entry width and sharpness of flare were established as the primary determinants of capacity/delay whilst a combination of entry deflection and entry width was their equivalent for safety. However, it is recognised that although roundabouts performed well in terms of overall safety, the involvement in accidents of pedal cyclists and motor cyclists at this junction type was relatively high. More recently, concerns about pedestrians and equestrians, and the prevention of large goods vehicle roll-over accidents at roundabouts have become issues.

1.2 Aim of project

The main objective of the project is to provide a comprehensive review of international roundabout design that will lead to a revised Design Standard to meet the needs of modern UK roads. The review considers the following issues:

- The need for different geometric design standards for roundabouts on rural and urban roads and developing a hierarchical approach
- Whether, and under what circumstances, “continental” roundabout designs, with much greater emphasis on vulnerable road users, might be introduced
- The case for outward crossfall
- Reviewing the current capacity calculation procedures (TD 16/93 Annex 1) and possible alternatives, including micro-simulation
- Concerns relating to the current standard
- The problem of large vehicle roll-over accidents

1.3 Report structure

Some countries have only recommended guidelines rather than a Standard. Some, e.g. the UK have full Standards that only apply to high class roads. Where possible, the review is based on the standards or guidelines for the country concerned that were current in Spring 2004. Details of Scandinavian designs were taken from conference proceedings because of difficulty in obtaining the relevant standards and to avoid the need for translation. They vary considerably in their level of detail, ranging from minimum dimensions and general recommendations to the prescription of different combinations of design dimensions, with the Australian and American guidelines providing methods for calculating dimensions rather than ranges of values. For simplicity, all are referred to as guidelines in what follows. It is not known to what extent recommended designs are adhered to.

Mini-roundabouts (which are capable of being driven over) are to be part of a separate UK standard, but a comparison of the key design elements is included for consistency.

Section 2 of the report gives an overview of the differences in design between different countries and the underlying rationale. Section 3 compares dimensions of individual design features in different countries, whilst Section 4 looks at safety studies. Section 5 considers roundabout modelling. Section 6 summarises the findings, whilst Section 7 outlines the new design hierarchy. Appendix A lists the key design parameters on a country-by-country basis.

2 Overview

2.1 Introduction

A roundabout consists of a number of arms spaced round a central island with a circulatory carriageway. In modern designs, vehicles entering the roundabout must give way to traffic from the right (in the UK) i.e. that already circulating, or entering from the previous arm at a small or mini-roundabout.

In the UK, all roundabouts have broadly the same design, whether they are mini-roundabouts or form part of a large grade-separated junction. Entry flaring, usually by adding either one or two lanes at the give way line, is recommended even if it is not required to increase capacity.

A typical UK roundabout layout is shown in Figure 1, with aerial views of three and four-arm roundabouts in Figures 2 and 3. Note the flaring from one to two or from two to three lanes.

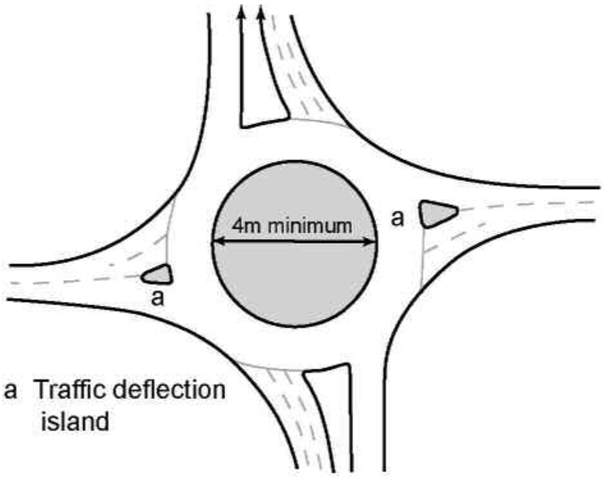


Figure 1: Plan of a typical UK 4-arm normal roundabout

	
Fig 2: Aerial view of typical UK 3-arm roundabout	**Fig 3: Aerial view of typical UK 4-arm roundabout**

2.2 Roundabout categories

Guidelines in countries other than the UK tend to categorise roundabouts by size, the distinction being between the number of lanes:

- Single lane roundabouts have one lane entries and exits on all arms, with a one lane circulatory carriageway

- Double lane roundabouts have two lane entries and exits on all arms and a two-lane circulatory carriageway
- Three lane roundabouts have three lane entries and exits on all arms and a three-lane circulatory carriageway (only in the Australian and French guidelines)

There are often separate designs or recommendations for rural and urban roads, and in some countries, for arterial and local roads. Mini-roundabouts and compact urban roundabouts are used mainly on local roads.

The categories used in this report to compare the different design guidelines are:

1. *Mini-roundabouts*
2. *Urban roundabouts*
    - 2a. Single lane
    - 2b. Double lane
3. *Rural roundabouts*
    - 3a. Single lane
    - 3b. Double lane

2.3 Capacity versus safety

Although the safety record of roundabouts is generally better than that of other junction types, roundabouts in the UK are mainly regarded as a high capacity junction. This tradition has led to large roundabouts with high speed circulating traffic.

In most other countries, roundabouts have been introduced much more recently. The main emphasis is on their speed-reducing capability and safe performance compared to other junction types, with the high capacity seen as a bonus. This emphasis on safety is, not surprisingly, reflected in the design standards. Roundabouts are usually smaller and the geometry tighter, than in the UK.

Features such as entry flares and segregated left turn lanes (right turn lanes in countries that drive on the right) that are used in the UK to increase capacity tend to be considered poor design in many countries, because they allow higher speeds.

Early examples of roundabouts other than in the UK were all single lane as these were expected to have a lower accident rate than double lane ones. This has been confirmed by various studies (e.g. Brüde and Larsson, 1999, both in Sweden, and van Minnen, 1998, in the Netherlands), although double lane roundabouts still have lower accident rates than other junction types (van Minnen, 1998). More recently, double lane (and occasionally three-lane) roundabouts have been introduced on dual-carriageway roads, although they are not universally recommended. It is known that some roundabouts in other countries have a mixture of single and double lane arms, but this design is not included in any of the guidelines.

The use of roundabouts for safety is particularly notable in Germany, France and the Netherlands. Scandinavian designs mainly address safety concerns, but are somewhat larger with less tight geometry. Herland and Helmers (2002) attribute these differences to a larger Swedish design vehicle.

Although safety aspects play an important role in roundabout design in Australia, more importance is given to capacity than in most countries on the European continent. Correspondingly, Australian designs show greater similarity to the UK.

Use of roundabouts in the USA is relatively recent and therefore design draws on guidelines from the UK, France and Australia. For larger roundabouts, greater emphasis is placed on the Australian and UK Standards, whereas for smaller roundabouts, design is more similar to that in Northern Europe. This is illustrated by the use of two types of urban single lane roundabout. The “urban compact” type is similar to designs in Germany, France and the Netherlands, whereas the design for arterials is closer to that used in Australia and the UK.

2.4 Design guidelines

The UK Standard is intended for trunk roads, but is widely used by local highway authorities. Some sections of the Standard are mandatory on trunk roads, others are advisory. Some of the information traced for other countries is in the form of recommended guidelines rather than a standard. Details of Scandinavian designs were taken from conference proceedings because of difficulty in obtaining the relevant standards and to avoid the need for translation. For simplicity, all of the sources are referred to as guidelines in this report. They vary considerably in the level of detail given, ranging from minimum dimensions and general recommendations to the prescription of different combinations of design dimensions. The Australian and American guidelines provide methods for calculating dimensions rather than a range of values.

3 Roundabout design features

3.1 Number of arms

In the UK, the recommended number of arms is 3 or 4, but larger roundabouts with more than 4 arms are relatively common. There is no mention of roundabouts with more than 4 arms in guidelines from most countries. However, it is known that these exist (e.g. France has roundabouts with up to 7 arms and the new German guidelines illustrate a 5-arm roundabout).

3.2 Central area of roundabout

3.2.1 Inscribed circle diameter

For a symmetrical roundabout, the *inscribed circle diameter* is the diameter of the largest circle that can be fitted into the junction outline (Figure 4). Where the outline is asymmetric, the local value in the region of the entry should be used.

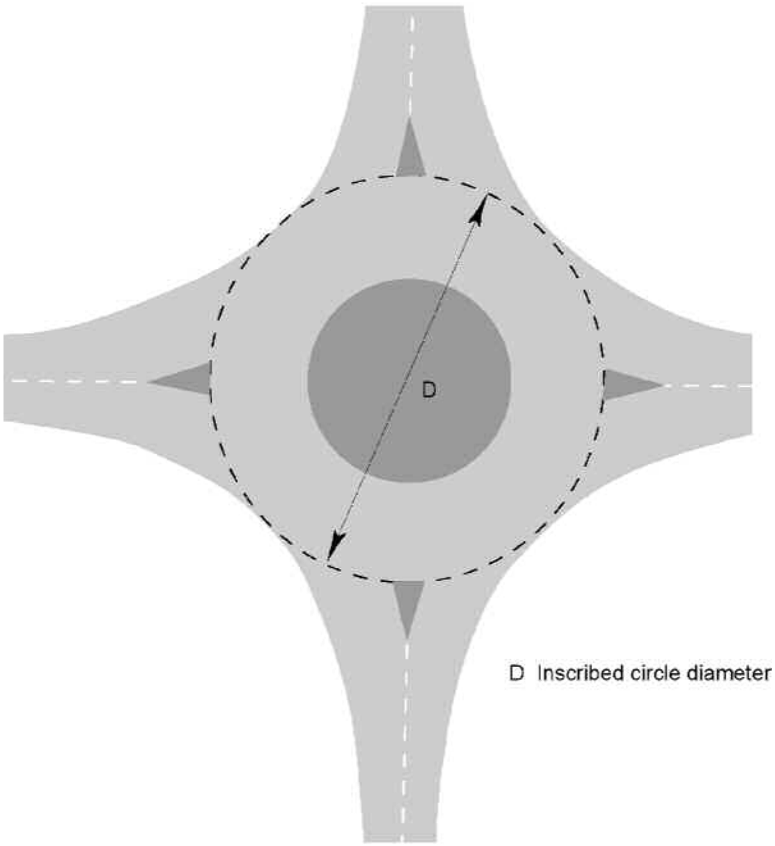


Fig 4: Inscribed circle diameter at a normal roundabout

UK roundabouts often have large inscribed circle diameters. This arose historically, from the 1960s when the priority rule was to give way to traffic entering the roundabout which could lead to gridlock when traffic demand was high and therefore long ‘weaving lengths’ were used. This tradition of designing for capacity also led to flaring and tangential entries. Although beneficial from the point of view of capacity, large roundabouts encourage higher speeds and increase geometric delay (journey time) not just for vehicles but also, in urban areas, for pedestrians, and for cyclists who cross as pedestrians. Roundabouts at grade separated junctions (Figure 5) are particularly large unless replaced by a ‘dumbbell’ interchange with a single bridge and two roundabouts (Figure 6).

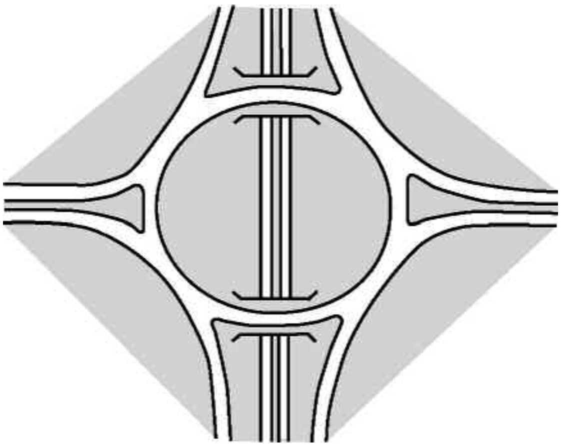


Fig 5: Grade separated roundabout

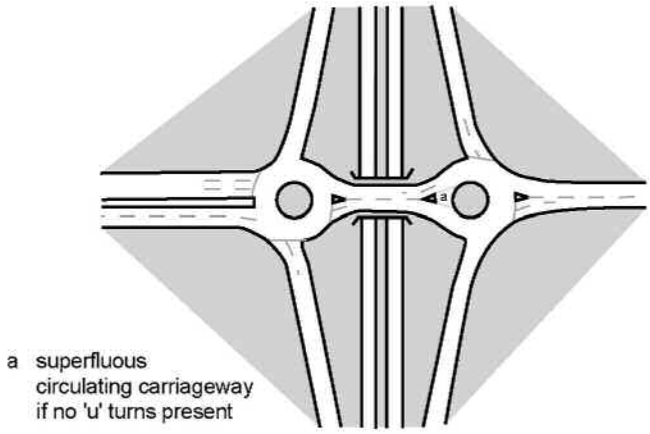


Fig 6: Dumbbell interchange

The UK standard recommends a minimum inscribed circle diameter of 28m for both urban and rural roundabouts. This is the minimum diameter that, with a central island diameter of 4m, can be negotiated by the design vehicle (a 15.5m long articulated vehicle with a single axle at the rear of the trailer). For inscribed circle diameters below this, a mini-roundabout should be used. No maximum is given in the standard, although the version of TD 16/93 used by Essex County Council advocates a maximum of 100m to avoid high circulating speeds. In practice, values for roundabouts at grade-separated junctions may exceed 250m. Many large roundabouts in the UK have been signalised in recent years, particularly grade-separated roundabouts of the design shown in Figure 5.

Other countries specify both a minimum and a maximum inscribed circle diameter, as shown in Table 1. Minima range from 24 to 36m. Maxima range from 30 to 90m for a single lane roundabout and from 20 to 90m for a double lane roundabout.

Table 1: Inscribed circle diameter

Country		Single lane Min (m)	Single lane Max (m)	Double lane Min (m)	Double lane Max (m)
Australia	Urban / rural	-	80	-	80
France	Urban	30	-	-	-
	Rural	24	30	24	50
Germany	Urban	26	35	40	-
	Rural	35	45	40	-
Netherlands	Urban / rural	32	32	20	38
	Rural	36	36	20	38
Norway	Urban / rural	26	45	26	45
Sweden	Urban / rural	30.8	90	30.8	90
UK	Urban / rural	28	-	28	-
USA	Urban	25-30	30-40	45	55
	Rural	35	40	55	60

Both Alphand et al (1991) in France and Brilon and Stuwe (1991) in Germany concluded that larger roundabouts have higher accident rates than smaller ones. The German definition of larger roundabouts was those with an inscribed circle diameter of 40 to 142m, with smaller roundabouts having an inscribed circle diameter of 28 to 40m.

Brüde and Larsson (1999) in Sweden found that a central island diameter greater than 50m increased accident risk and suggested that a diameter between 20 and 50m is probably optimal. Islands with diameters of less than 10m often give a straight driving path with potentially high speeds, whilst those with diameters greater than 50m also result in straighter paths, enabling higher speeds.

- *Conclusion: The inscribed circle diameter should not be unnecessarily large. If the roundabout is at-grade, it should not exceed 100m.*

3.2.2 Shape of central island

Most guidelines advise against the use of non-circular central islands, which arise mainly for historical reasons or where roundabouts are conversions from other junction types rather than being new-build. Alphand et al (1991) concluded from an analysis of accidents in France that oval shaped roundabouts had considerably higher accident rates than circular ones.

3.2.3 Width of circulatory carriageway

The *width of the circulatory carriageway* is determined by the maximum entry width and should be constant. In the UK, flared entries give rise to a circulatory carriageway that tends to be wider than in many other countries (Table 2), with values ranging from 1 to 1.2 times the maximum entry width, up to a maximum of 15m. The maximum recommended width for double lane roundabouts in the guidelines studied (other than in the UK) is 10.8m. As might be expected, rural values tend to be larger than urban ones. Circulatory carriageways in Germany and the Netherlands are the narrowest, with those in France more similar to the UK.

Table 2: Width of circulatory carriageway

Country		Single lane Min (m)	Single lane Max (m)	Double lane Min (m)	Double lane Max (m)
Australia	Urban / rural	4.6	7.6	8.4	10.3
France	Urban	6-7	9	7	9
	Rural	6	9	7.2 - 8.4[2]	10.8[2]
Germany	Urban	4.65	5.6	-	-
	Rural	5.75	6.5	-	-
Netherlands	Urban	5.5		8	10
	Rural	5.25		8	10
Sweden	Urban / rural	5	10.4	5	10.4
UK[1]	Urban / rural	7.2	15	10.8	15
USA	Urban / rural	calculated		8.7	9.8

1 UK minima are based on 1.2 x an entry width of 6m for single carriageways (2 lanes of 3m width) and 1.2 x 9m (3 lanes of 3m width) for dual-carriageway roads

2 Double lane roundabouts are not recommended; dual-carriageway roads should be narrowed upstream of the junction (lower value only where heavy vehicle flow is very low)

3 Australia also gives values for 3-lane roundabouts

3.2.4 Central island diameter

The inscribed circle diameter, the width of the circulatory carriageway and the *central island diameter* are not independent, the third being determined automatically once the other two are decided. In the UK, a mini-roundabout should be used where the central island diameter is 4m or less. Most normal roundabouts have considerably larger values for the central island diameter. In other countries, the range is from a minimum of 5m to a maximum of 80m – although not all countries give a maximum value (Table 3). Where quoted, Germany and the Netherlands have low maxima, with Norway and Sweden allowing rather higher values.

Table 3: Central island diameter (including truck apron where applicable)

Country		Single lane Min (m)	Single lane Max (m)	Double lane Min (m)	Double lane Max (m)
Australia	Urban / rural	5	8-10+	5	10+
France	Urban	5	18	-	-
	Rural	16	-	30	-
Germany	Urban	14.6	25.7	10	-
	Rural	22	33.5	10	-
Netherlands	Urban	21	21	10	30
	Rural	25.5	25.5	10	30
Norway	Urban / rural	>5	>25	>5	>25
Sweden	Urban / rural	10	80	10	80
UK	Urban / rural	4	-	4	-
USA	Urban / rural	Depends on design vehicle		25.4	41.8

3.2.5 Truck apron

A *truck apron* is a raised low profile overrun area around the central island used at small roundabouts where large vehicles would otherwise have trouble negotiating the roundabout (Figure 7). It is designed to be capable of being mounted by large vehicles, but unattractive to light vehicles e.g. by having a kerbed edge or by using cobblestones. It can also help to increase deflection for light vehicles.

a Main central island
b Central overrun area, where provided
c Remaining circulatory carriageway width = 1.0-1.2 x maximum entry width
d Vehicle
e 1m clearance minimum
f Inscribed Circle Diameter

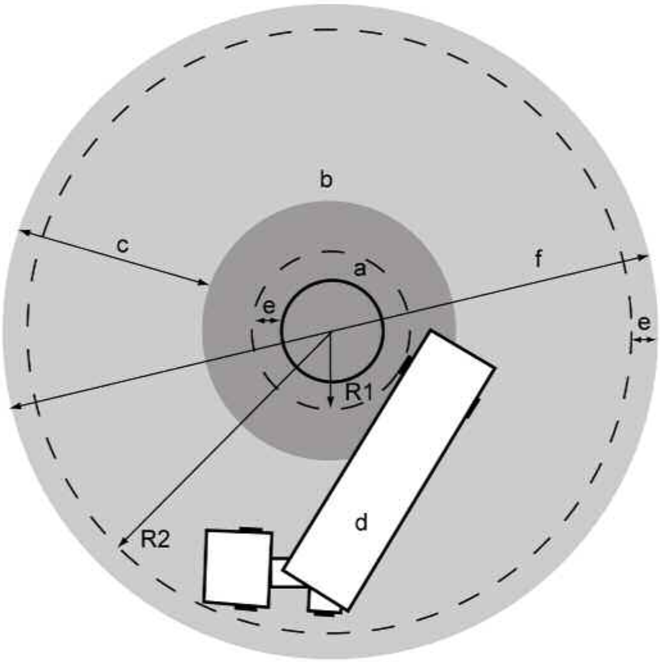


Fig 7: Use of trunk apron at small island roundabout

TD 16/93 allows the use of a truck apron at sites with a small inscribed circle diameter, to enable the design vehicle to negotiate the roundabout. There is an inconsistency in that TD 16/93 allows the edge profile to be up to 50mm, whereas according to the Traffic Calming Regulations, the vertical face should not exceed 15mm (6mm for the edge of a mini-roundabout).

There are anecdotal reports of problems with truck aprons:

- Motorcyclists, particularly in the dark, may fail to notice them
- Edges may require maintenance (Figures 8 and 9)

France and the Netherlands recommend truck aprons for both urban and rural single lane roundabouts, whereas Germany, USA and Australia recommend them only in urban areas (US and Australia only for “urban compact” roundabouts).

Australia also allows truck aprons on rural double lane roundabouts but “only when “over-dimensional” vehicles are expected”.

Conclusion: Truck aprons should continue to be used where it is important to minimise land-take but a mini-roundabout is not suitable. The vertical face of the truck apron should comply with the Traffic Calming Regulations. The surface should be sloping and/or textured in order to discourage light vehicles from mounting the apron.

Fig 8: Truck apron used at roundabout at Heworth Green, York (photograph from York City Council)

Fig 9: Truck apron at "continental-style" roundabout in Nottingham (photograph from Nottinghamshire County Council)

3.2.6 Crossfall

All guidelines studied other than TD 16/93 recommend outward crossfall of 1.5 to 3% on the circulatory carriageway. This is considered to aid drainage and make the circulatory carriageway more visible.

By contrast, most roundabouts in the UK have inward crossfall of 2-2.5% close to the central island, allowing drivers taking the second exit to maintain a relatively high speed through the junction. Inward crossfall close to the central island can be achieved in various ways:

(a) dish-shaped roundabout

(b) crown line joining deflection islands (Figure 10)

(c) crown line dividing the carriageway in the ratio 2:1 (Figure 11)

(d) two crown lines (Figure 12)

There is concern in the UK that outward crossfall may increase accident risk, and might affect large vehicle rollover. The latter is considered to be a problem at roundabouts where the crown line is not smooth.

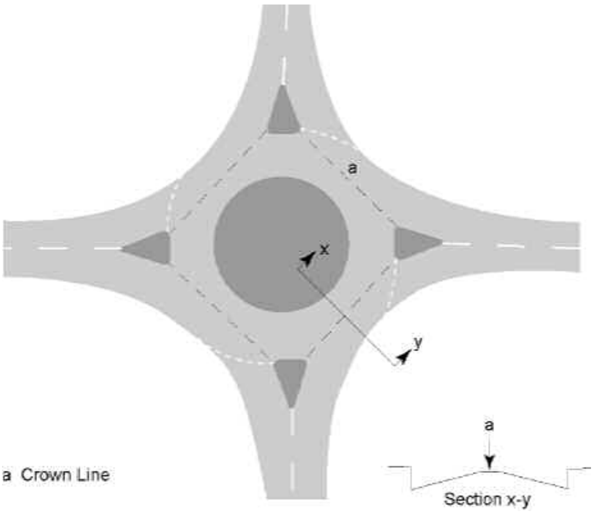


Fig 10: Using one crown line to join traffic deflection islands

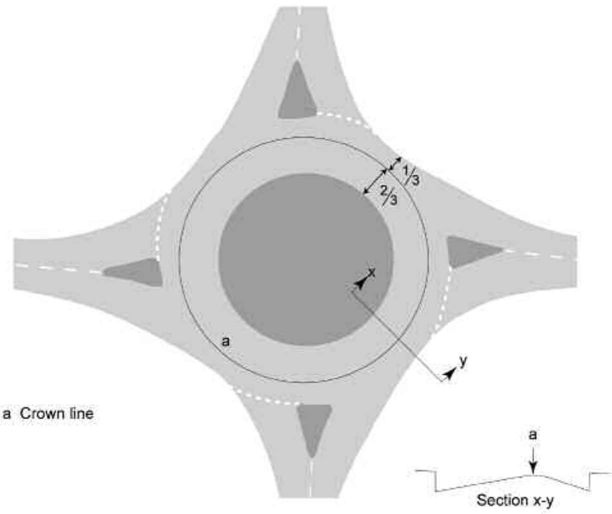


Fig 11: Using one crown line to divide the carriageway in the ration 2:1

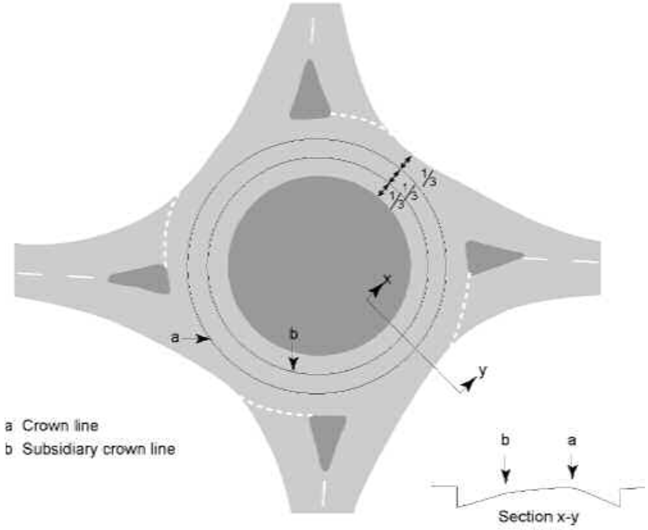


Fig 12: Using two crown lines

Crown lines mean that a vehicle may have to cross a ‘ridge’ at an angle from one camber to another, possibly leading to an increased likelihood of rollover for heavy goods vehicles because of the high centre of gravity and the need to negotiate a bend at the same time as the change in camber. Research has shown that articulated vehicles can overturn at speeds as low as 15mph on a bend.

Unpublished research by TRL and MVA suggests that a change from inward to outward crossfall would have only a small effect on speed, and therefore the use of outward crossfall should be primarily for reasons other than limiting speed, i.e. to increase conspicuity of the central island and to ease construction (Figure 13).

In icy or wet conditions, vehicles may start to slide at much lower values of lateral acceleration than in dry conditions and use of outward crossfall may decrease the safety margin, particularly for two-wheelers. Similarly the likelihood of rollover for heavy goods vehicles may be increased unless speeds are kept low. There is therefore concern that use of outward crossfall should not be advocated at rural roundabouts, or without changes in geometry at urban roundabouts.

Research from France, quoted in NCHRP 264 (1998) and reproduced in Table 4 below, suggests that inward crossfall is associated with a higher accident frequency. However the table quotes only accident frequencies and takes no account of traffic flow.

Table 4: Accident frequency with inward and outward crossfall at French roundabouts

	Inward crossfall (42 roundabouts)	**Outward crossfall 21 roundabouts)**
Total accidents per year per roundabout	0.50	0.28
Accidents due to loss of control on entry	0.12	0.06
Accidents due to loss of control on the circulatory carriageway	0.09	0.00
Entering-circulating accidents	0.14	0.09

If a truck apron is provided, an outward slope of between 3 and 4% is recommended to discourage their use by other motorists. It is noted in the French Setra guidelines that if the gradient were any steeper, it could result in trucks shedding their load.

In summary, outward crossfall could be permitted in the UK, where circulating speeds are likely to be low. The ease in construction would apply particularly to sites on a gradient, where it is often very awkward to build inward crossfall.

There are already a small number of UK roundabouts with outward crossfall:

a) A4010 junction with Cressex Road (High Wycombe, Buckinghamshire, close to M40 J4), 4-arm, with single lane entries, central island diameter of 14m

b) Junction of Parley Drive and St Johns Road (Woking, Surrey), 5-arm

c) A31(T) / A341 roundabout (Wimborne Minster, Dorset), 4-arm, large with high proportion of goods vehicles

d) A26/A275 roundabout (Lewes, East Sussex), 3-arm (see Figure 14)

The accident history for sites a, b and c showed no particular problems. The accident history has not been obtained for site d.

Conclusion: Outward crossfall should be allowed on smaller urban roundabouts.

Fig 13: French roundabout near Boulogne with outward crossfall (photo courtesy C Sawers)

Fig 14: UK roundabout with outward crossfall A26/A275 roundabout - Lewes, East Sussex (photo courtesy C Sawers)

3.3 Entries and exits

3.3.1 Deflection or splitter island

All guidelines recommend the use of *deflection or splitter islands* on the approaches to roundabouts. The islands are generally kerbed (sometimes hatched at mini-roundabouts) and are usually shaped so as to deflect traffic to ensure it passes the central island on the correct side. In urban areas where speeds are lower, France, Germany and the Netherlands have radial arms with splitter islands parallel to the entering arm.

The French guidelines list the main purposes of a splitter island:

(i) it increases driver awareness of the intersection;
(ii) it can act as a pedestrian refuge;
(iii) it separates the entry and exit movements;
(iv) it increases capacity since exiting drivers can be identified earlier;
(v) road signs can be sited there;

(vi) it limits the risk of 'going the wrong way' round the central island

Several countries, notably the UK, USA and Australia recommend that, particularly in rural areas, the kerbline should lie on an arc which, when projected forward, either meets the central island tangentially or passes to the left of it. There is strong anecdotal evidence that failure to do this can lead to single vehicle accidents on high speed roads. TD 16/93 states that care should be taken to ensure that as a result, entry path curvature is not too great and the entry angle is not too low. Some local authorities in the UK, notably Kent, allow the projected kerbline to bisect a radius of the central island (Figure 15).

Conclusion: Except at small urban roundabouts, the kerbline of the deflection island or median should be on an arc which, when projected forward, meets the central island tangentially, in order to reduce he likelihood of vehicle paths overlapping.

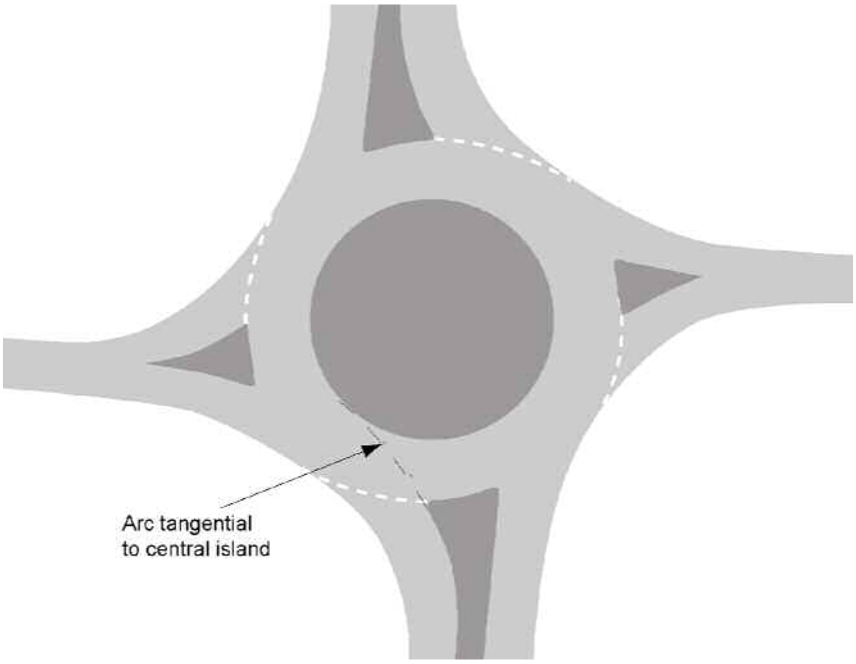


Figure 15: Example of how the arc projected from the splitter island meets the roundabout

3.3.2 Radial or tangential entries

The UK standard shows roundabout arms as radial, but in practice the combination of the use of flaring and the recommended values for entry angle tend to creates tangential entries. For the purposes of comparison with other countries in Appendix A, this arrangement is described as tangential.

Continental designs have radial arms in urban areas. Swedish guidelines recommend radial entries and tangential exits. Australian has tangential entries and exits, the entries following the projected curve of the splitter island and the exits tangential to the central island.

3.3.3 Entry width

Entry width is defined as the length of a perpendicular from the corner of the splitter island to the nearside kerb (Figure 16). For capacity and safety assessment, it should be the width used by drivers. The maximum value in TD 16/93 is 10.5m for single and 15m for dual-carriageways (Table 5).

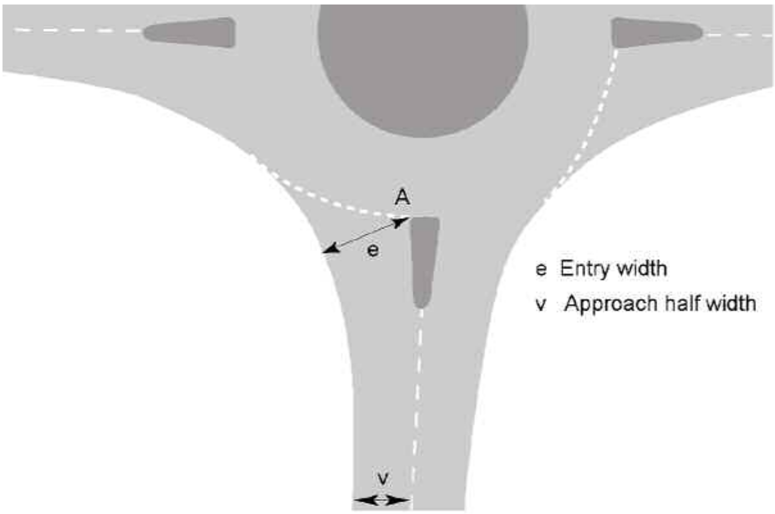


Fig 16: Approach half width and entry width

Wider entries tend to increase both capacity (Kimber, 1981) and accident risk (Maycock and Hall, 1984). As roundabouts are often designed for flows in 15 years time, there may be operational problems if flows in the early years are low. In this case, the standard suggests that not all lanes should be made available initially.

Kimber (1981) measured the capacity of roundabouts in the UK and suggested that it is entry width rather than the number of lanes at entry that increases capacity. The standard requires lanes to be not less than 3m wide at the give way line. The West Midlands Region Road Safety Audit Forum (1997) suggests that lane widths should be between 3 and 4m. Both TD 16/93 and the French guidelines state that additional narrow lanes do not increase capacity and do increase accident risk.

Other countries mainly recommend values between 3 and 5m for single-lane roundabouts.

For double lane roundabouts, Australia recommends a width of between 3.4 and 4m per lane. France recommends widths between 6 and 7m for urban and 6 and 9m for rural double lane roundabouts. The Dutch guidelines recommend improving safety by narrowing entries to single lane with a maximum width of 4m.

Conclusion: Lane widths at entry should remain at 3 to 3.5m at multilane entries, but at single lane entries, the width should be 4.5m.

Table 5: Entry width

Country		Single lane Min (m)	Single lane Max (m)	Double lane Min (m)	Double lane Max (m)
Australia	Urban / rural	3.4	4 - 5	6.8	8
France	Urban	2.5 - 3	4	6	7
	Rural	4	4	6 - 7	9
Germany	Urban	3.25	3.5	-	-
	Rural	3.5	4	-	-
Netherlands[1]	Urban / rural	3.5	4	3.5	4
Sweden	Urban / rural	3.5	3.5	7	7
UK[2]	Urban / rural	-	-	-	10.5
USA	Urban / rural	4.3	4.9	6	-

1 In the Netherlands, 2 lane entries on dual-carriageway roads are permitted, but not recommended

2 In the UK, widespread use of flaring means that very few roundabouts are single lane entry

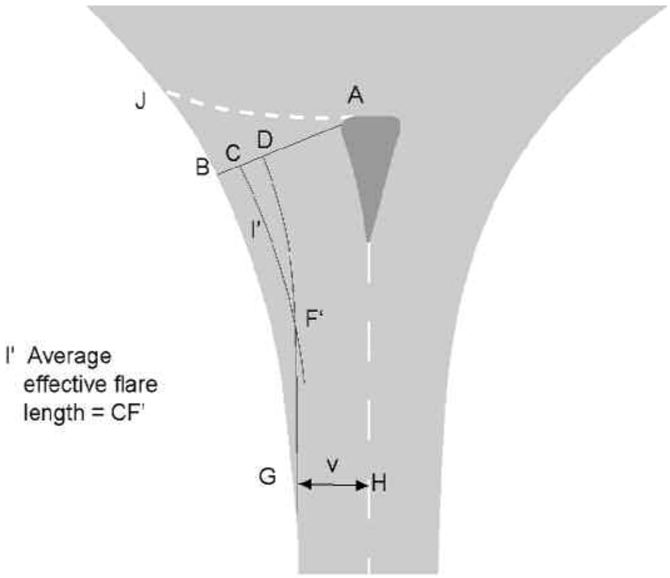
3.3.4 Entry flare

Entry flaring is the widening of the entry from the approach half width to the entry width. TD 16/93 states that it is good practice at normal roundabouts to flare entries to allow multiple vehicle entry. Mini-roundabouts may be with or without flared entries. The *sharpness* (S) of the flare is given by:

$$S=1.6(e-v)/l'$$

and is a measure of the efficiency of the flare. If there is no flare on an entry, only the approach width is used by traffic. If there is a long gradual flare, then all of the available entry width can be used. Where there is no need for additional capacity, use of a flare in the UK is largely historic, being originally intended to allow for the frequent breakdown of cars at the give way line (Brown, 1996).

In the UK, the *effective flare length* i.e. the effective length over which the entry widens is calculated as shown in Figure 17. The maximum value is 100m, with little benefit beyond 25m (Kimber, 1981). Effects beyond 30-40m are based on extrapolated data. Suggested flare lengths are 5m in urban areas and 25m in rural areas.



Notes:

1. AB = e (entry width)
2. GH = v (approach half width at point G which is the best estimate of the start of the flare)
3. GD is parallel to AH and distance v from AH (v is measured along a line perpendicular to both AH and GD and therefore the length of AD is only equal to v if AB is perpendicular to the median at A)
4. CF' is parallel to BG and distance ½ BD from the kerbline BG

Figure 17: Average effective flare length

To determine the average *effective flare length*, l':

- Construct curve GD parallel to the median HA (centre line or edge of central reserve or splitter island) and distance v from it
- Construct curve CF' parallel to curve BG (the nearside kerb) and at a constant distance of ½ BD from it, with F' the point where CF' intersects line DG
- The length of curve CF' is the average effective flare length l'.

In cases where the line AB is NOT perpendicular to the median, the length AD will differ slightly from v.

By contrast, with the exception of Australia, most countries advise against the use of flares at roundabouts, although they are permitted in Germany, Switzerland and the US as an intermediate between single lane and double lane roundabouts. In the US, recommended flare lengths are 40m in urban and 50m at rural roundabouts; however, it is not clear how flare lengths are calculated in the US.

Shorter flares, or the absence of a flare, tend to aid pedestrians by reducing geometric delay (journey time) for pedestrians crossing the road. They are also likely to aid cyclists whether they mix with traffic or cross as pedestrians.

Conclusion: Adding an extra lane at roundabout entries in the UK should require justification rather than being automatic. The average effective flare lengths of 5m (urban) and 25m (rural) should remain.

3.3.5 Entry kerb radius

The *entry radius (or entry kerb radius)* is defined as the minimum radius of curvature of the nearside kerb line in the region of the entry (Figure 18). In TD 16/93, a value in the range 6 to 100m is recommended, with a minimum of 10m if there are large goods vehicles. Large entry kerb radii can lead to high entry speeds, because it is difficult to get sufficient deflection. A value of 20m is considered good practice.

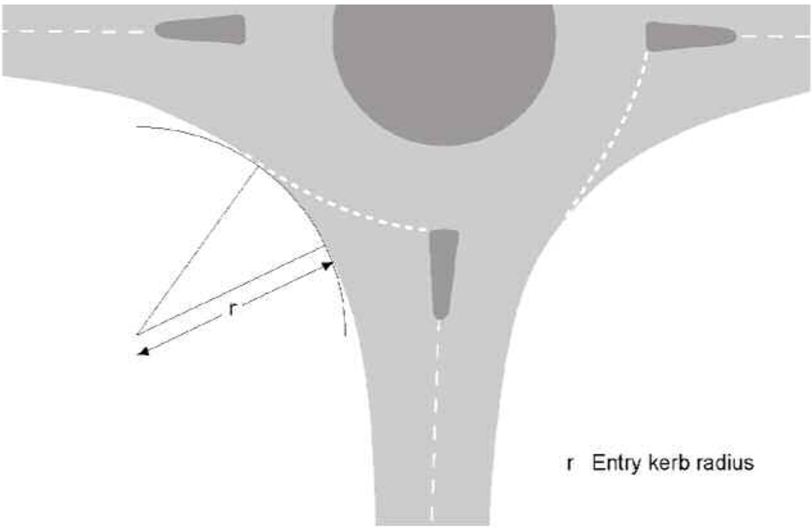


Fig 18: Entry kerb radius

For single lane roundabouts, the maximum recommended entry radius in the German, French and Dutch guidelines is 15m (Table 6). The French value is also required to be less than the radius of the inscribed circle. A typical entry radius for both urban and rural roundabouts in Norway is 20m, comparable with the UK. Most countries have minimum radii that are higher than in the UK, the exceptions being “urban compact” roundabouts in the US and “speed reducing” roundabouts in Sweden. For roundabouts in rural areas, Australian guidelines recommend an entry radius greater than 30m.

For double lane roundabouts, Australian and Norwegian guidelines recommend entry radii that are comparable to, or larger than, the UK value of 20m; the Dutch and French guidelines recommend entry radii in the range 12 to 20m (French guidelines for rural double lane roundabouts only).

Conclusion: Use 20m for the entry kerb radius at larger roundabouts, 10-15m at small roundabouts.

Table 6: Entry radius

Country		Single lane Min (m)	Single lane Max (m)	Double lane Min (m)	Double lane Max (m)
Australia	Urban / rural	-	-	30	-
France[1]	Urban	8	15	8	15
	Rural	10	15	10	15
Germany	Urban	10	12	-	-
	Rural	12	14	-	-
Netherlands	Urban / rural	8	12	12	12
Norway[2]	Urban / rural	10	100	10	100
Sweden	Urban / rural	8	25	8	25
UK[2]	Urban / rural	6	100	6	100
USA	Urban	10	30	calculated	
	Rural	calculated		calculated	

1 In France, the entry radius must be less than the radius of the inscribed circle

2 UK and Norway typically use 20m

3.3.6 Exit width

Exit widths are typically similar to, or slightly less than, entry widths (i.e. exits tend to have less flaring), as shown in Table 7 and illustrated in Figure 19. TD 16/93 states that the ‘principle of easy exits’, i.e. the need to provide a clear exit route with sufficient width to avoid conflicts, applies. Large exit radii making exits tangential assist this (see Section 3.3.10). However, they tend to increase exit speeds and this may be undesirable e.g. in urban areas where there are pedestrians.

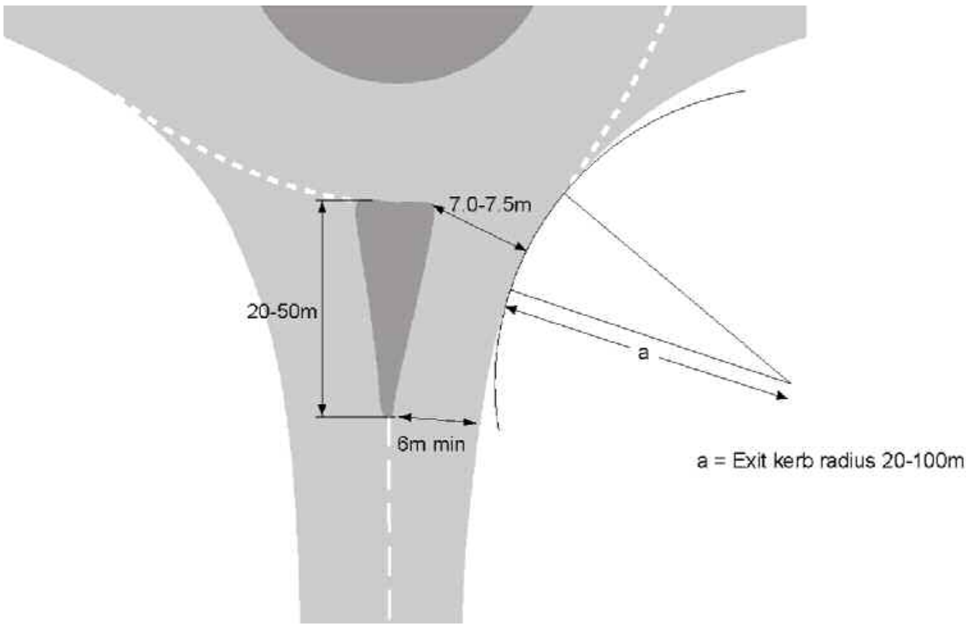


Fig 19: Typical single carriageway exit at a normal roundabout with a long splitter island

Table 7: Exit width

Country		Single lane Min (m)	Single lane Max (m)	Double lane Min (m)	Double lane Max (m)
Australia	Urban / rural	4	5	6.8	8
France	Urban	4	4.5	-	-
	Rural	4	5	6	7
Germany[1]	Urban	3.25	3.75	-	-
	Rural	3.5	4.25	-	-
Netherlands[2]	Urban / rural	4	4.5	4[1]	4.5[1]
Sweden	Urban / rural	3.5	4.5	7	7
UK	Urban / rural	7-7.5		10-11	

1. Double lane exits are not recommended in Germany unless roundabout is signalised
2. Double lane exits are not recommended in the Netherlands even on dual carriageway roads

3.3.7 Exit (kerb) radius

The *exit radius* (or exit kerb radius) is defined in a similar manner to the *entry kerb radius*. The perpendicular from the corner of the deflection island to the kerb defines the region where exit radius should be determined. The UK standard recommends an exit kerb radius between 20 and 100m, with 40m a suitable average.

German and Dutch exit radii are smaller than in the UK, ranging from 12 to 20m (Table 8). French guidelines recommend 15 to 20m in urban areas and 15 to 30m for rural areas.

Norway and USA recommend exit radii comparable with those in the UK with those in Sweden much larger. Australian guidelines recommend exits “as easy to negotiate as practicable”.

Conclusion: Use 20-100m for the exit kerb radius at larger roundabouts, 15-20m at small roundabouts.

Table 8: Exit radius

Country		Single lane Min (m)	Single lane Max (m)	Double lane Min (m)	Double lane Max (m)
Australia	Urban / rural	-	-	-	-
France[1]	Urban / rural	15	20	15	20
Germany	Urban	12	14	-	-
	Rural	14	16	-	-
Netherlands	Urban / rural	12	15	15	15
Norway[2]	Urban / rural	20	100	20	100
Sweden	Urban / rural	100	200	100	200
UK[2]	Urban / rural	20	100	20	100
USA	Urban / rural	10-15	calculated	10-15	calculated

1 Must be greater than radius of central island

2 UK and Norway typically use 40m

3.3.8 Entry angle

The *entry angle (φ)* is used in the UK as a geometric proxy for the conflict angle between the entering and circulating traffic. There are three separate definitions in TD 16/93. The first applies to large roundabouts where the arms are well separated and the circulatory carriageway is curved (Figure 20). The second applies to old style roundabouts where the circulatory carriageway between an entry and the next exit is approximately straight (Figure 21). This should probably be removed from the Standard as being outdated. The third applies to smaller, modern design, roundabouts (Figure 22).

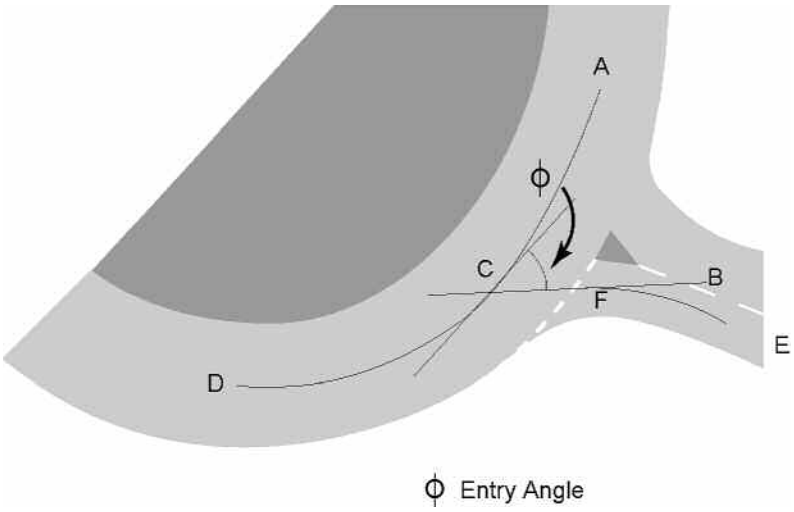


Fig 20: Roundabout with curved circulatory carriageway

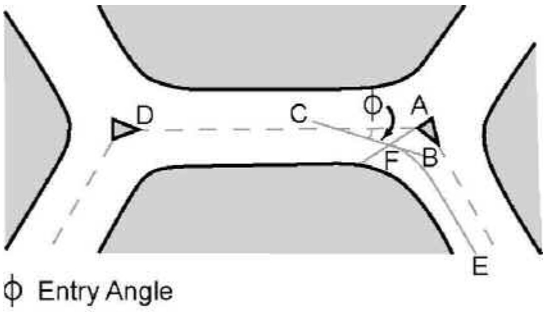


Fig 21: Roundabout with straight circulatory carriageway

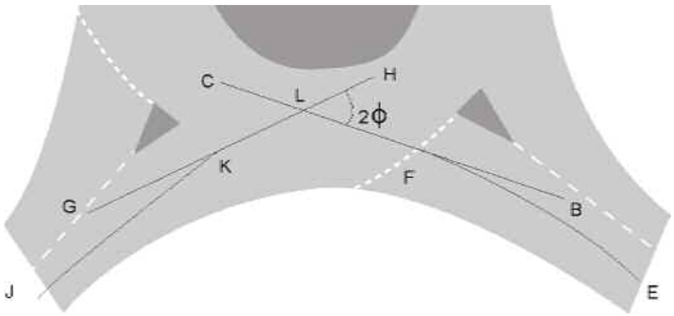


Fig 22: Modern design small roundabout

Figure 22 shows how the entry angle is measured for a large roundabout. The curve A'D' is the locus of the mid-point of (the used section of) the circulatory carriageway and is a proxy for the average direction of travel for traffic circulating past the arm.

- Construct the curve EF as the locus of the mid-point between the nearside kerb and the median line (or the edge of any splitter island or central reserve)
- Construct BC as the tangent to EF at the give way line
- Construct the curve AD as the locus of the mid-point of (the used section of) the circulatory carriageway (a proxy for the average direction of travel for traffic circulating past the arm)
- The entry angle, φ, is the acute angle between BC and the tangent to AD.

Where the circulatory carriageway between an entry and the next exit is approximately straight, the entry angle is measured as shown in Figure 23. AD is parallel to the straight circulatory carriageway, where A is the point of maximum entry deflection at the right hand end of the give way line and D is the point nearest to A on the median of the following entry. AD replaces the tangent to the curve A'D' as the line from which the angle is measured at the point of intersection.

For smaller roundabouts, the entry angle is measured as shown in Figure 24. This construction is used when there is insufficient separation between entry and adjacent exit to be able to define the path of the circulating vehicle clearly. In this case, circulating traffic which leaves at the following exit will be influenced by the angle at which that arm joins the roundabout. The angle between the projected entry and exit paths is measured and then halved to find φ:

- Construct line BC as in Figure 22.
- Construct the curve JK in the next exit as the locus of points midway between the nearside kerb and the median line (or the edge of any splitter island or central reserve).
- Construct the line GH as the equivalent of line BC i.e. the tangent to the curve JK at the point where JK intersects the border of the inscribed circle.
- The lines BC and GH intersect at L. The entry angle, φ, is half of angle HLB.

$$\varphi = [\text{angle HLB}]/2$$

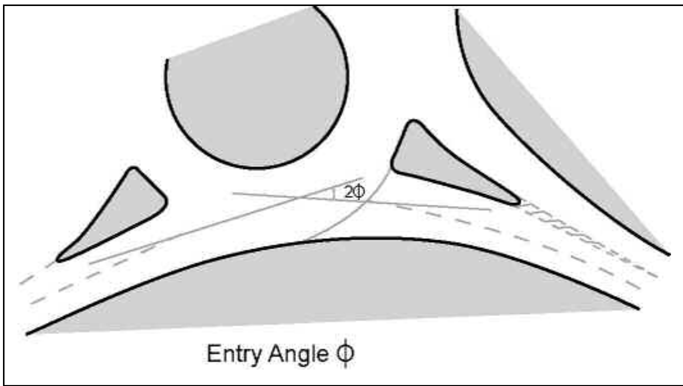
Note that if angle GLB exceeds 180 degrees, φ is defined as zero.

Conclusion: The case shown in Figure 21 is no longer built and should be removed from the standard.

A method to clarify which procedure should be used was derived as part of an unpublished study into roundabout capacity by the University of Southampton. The three vehicle paths (entry, exit and circulatory carriageway medians) should be constructed, and the entry and exit paths projected towards the roundabout centre. The choice of construction for φ depends on where these projections meet: if the meeting point is closer to the centre of the roundabout than the arc of the circulatory carriageway median, then the construction shown in Figure 21 should be used; if they meet outside that area, then the construction illustrated in Figure 23 should be used. In the limiting case where all 3 medians intersect at a point, it is common for the circulatory carriageway median approximately to bisect the angle between the other two medians, so that the two methods become equivalent.

The recommended range in TD 16/93 is 20 to 60 degrees, but some local authorities recommend 30 to 40 degrees and The West Midlands Region Road Safety Audit Forum (1997) recommends 30 degrees. Small values may result in too little entry deflection (Figure 23) and may cause a problem for right hand drive vehicles or for older drivers who may have trouble looking over their shoulders. Large values may result in excessive entry deflection (Figure 24); in rural areas, this may lead to vehicles hitting the central island or braking sharply, possibly causing shunt accidents. It is not clear whether both definitions of entry angle have a similar recommended range. Guidelines in other countries do not refer to entry angle. Davies et al (1997) suggest that a value of approximately 30 to 45 degrees is consistent with continental roundabout design.

Conclusion: Continue to allow the full range of 20 to 60 degrees for the entry angle particularly at smaller roundabouts.



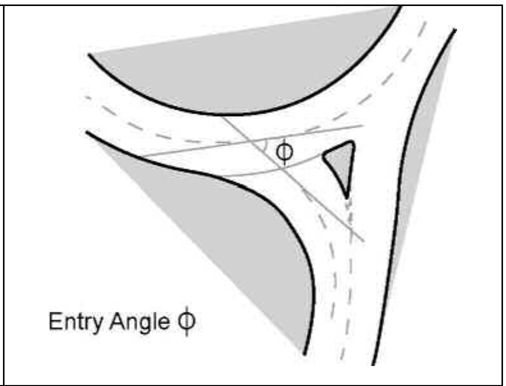


Fig 23: Example of too low an entry angle and also substandard entry deflection	**Fig 24: Example of too high an entry angle and also excessive entry deflection**

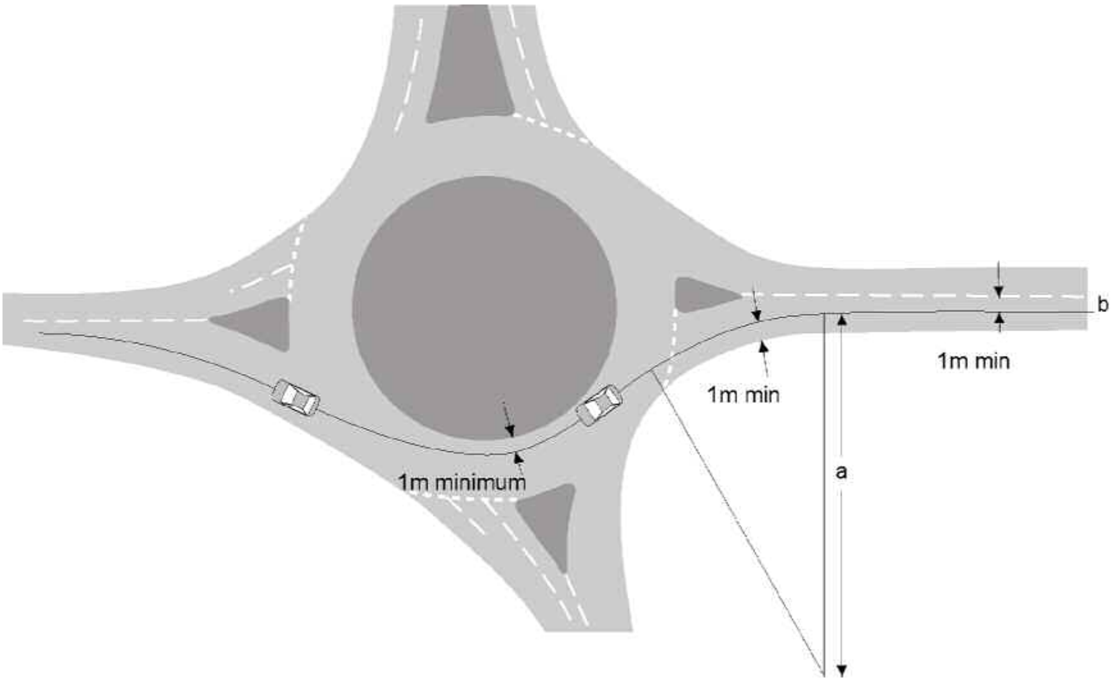
3.3.9 Segregated left turn lane

Segregated left turn lanes (right turn in countries that drive on the right) now form part of a separate standard in the UK (DMRB 6.3.5 TD 51/03) and, in addition to flaring, are a recognised method of increasing capacity at roundabouts where a high proportion of the flow turns left. The French, Dutch, German and American guidelines all advise that they can lead to high speeds. In the latter two guidelines, a segregated left turn lane is recommended in preference to flaring at single-lane roundabouts where there is a need to increase capacity.

Conclusion: Continue to use flaring in preference to a segregated left turn lane as this requires less land take and is more appropriate in urban areas.

3.3.10 Entry path curvature and design speed

Entry path curvature is a measure of the deflection at an entry to a roundabout and is one of the key variables used for accident prediction in the UK (Maycock and Hall, 1984). It was originally defined at a 4-arm roundabout for a vehicle taking the fastest ‘ahead’s path in the absence of other traffic (Figure 25). The vehicle follows a 2m wide path keeping to its own side of the road but otherwise ignoring lane markings, keeping the centre of the path at least 1m from the kerb. The entry path curvature is the maximum value occurring in the region of the give way line, that is, the inverse of the minimum *entry path radius*.



a Entry path radius should be measured over the smallest best fit circular curve over a distance of 25m occurring along the approach entry path in the vicinity of the give way line, but not more than 50m in advance of it.

b Commencement point 50m from the give way line and at least 1m from the nearside kerb or centre line (or edge of central reserve)

Figure 25: Measurement of entry path radius

Entry path radius is measured as follows:

Draw the fastest vehicle path allowed by the geometry. This is the smoothest, flattest path that a vehicle can take through the entry, round the central island and through the exit (in the absence of other traffic) (see Figure 27).

The path is assumed to be 2m wide so that the vehicle following it would maintain a distance of at least one metre between its centreline and any kerb or edge marking. The path starts 50m in advance of the give way line.

The entry path radius is the smallest radius of this path on entry that occurs as it bends to the left before joining the circulatory carriageway. It is the radius of the best fit circular curve over a length of 25m, measured in the vicinity of the give way line. It is.

In TD 16/93, a value of 100m for the entry path radius is suggested, broadly equivalent to an entry speed of 30mph (50km/h), with 60m more typical at urban roundabouts. No minimum is quoted, but it is not considered good practice to use very low values because of the increased risk of single vehicle accidents. A minimum of 70m is suggested by the West Midlands Region Road Safety Audit Forum (1997).

In both France and Australia, the maximum value of the entry path radius is also 100m (Table 9).

The Australian and US guidelines for double lane roundabouts are based on a 2m wide vehicle path for which the centre passes no closer than 2.5m from the central island compared with the 1m value used in the UK.

Table 9: Entry path radius

Country		Single lane Min (m)	Single lane Max (m)	Double lane Min (m)	Double lane Max (m)
Australia	Urban / rural	-	100	-	100
France[1]	Urban	-	100	-	100
	Rural	48	100	48	100
UK	Urban / rural	-	100	-	100
USA	Urban / rural	54	73	65	93

1 Rural France – 4 x radius of inscribed circle

Other countries specify design speeds rather than entry path curvature to assess deflection. Switzerland (Spacek, 2004) defines the 'angle of deflection' as the angle between the approach centre line and the tangent to the central island. Kennedy et al (1998) used angles as a measure of deflection at mini-roundabouts.

The American and Australian guidelines give details of the approximate relationship between path radius and design speed as follows:

$$V^2 = 127 R (e + f) \qquad (1)$$

where:

V is the design speed through the roundabout in km/h

R is the radius of the path in m

e is the super elevation in m/m (negative for outward crossfall)

f is the coefficient of friction developed between the vehicle tyres and the road

Suggested values for f in Australia are 0.2 at 50km/h and 0.3 at 25km/h. Calculations using equation show that the predicted effect of 2% crossfall on speed is relatively small (Section 3.2.6).

Table 10 compares recommended design speeds on entry in different countries. Where the design speed on the circulatory carriageway itself is specified separately, it is either equal to or less than the design speed on entry to the roundabout.

Conclusion: Entry path radius should apply to the fastest movement through the junction rather than simply that between opposite arms at a 4-arm roundabout or across the head of the T at a 3-arm roundabout. Continue to use 100m for the maximum entry path radius at most roundabouts, 70m at compact urban roundabouts.

Table 10: Recommended design speed on entry (km/h)

Country		Single lane	Double lane
Australia	Urban / rural	<65km/h and no more than 10-15km/h above speed on rdbt	
Denmark	Urban	15	N/A
France	Urban	35	50
	Rural	50	50
Germany	Urban / rural	20-40	-
Netherlands	Urban	30	40-45
	Rural	30-35	40-45
UK[1]	Urban / rural	50	50
USA	Urban	25-35	40
	Rural	40	50

1 50km/h (30mph) is taken to be equivalent to an entry path radius of 100m

3.3.11 Approach curvature and alignment

Approach curvature is a measure of the amount of curvature in advance of any flaring. It affects vehicle speeds on the approach to the roundabout. It can be positive or negative depending on whether the nearest bend is to the right or the left.

It is not good practice to generate entry deflection by sharply deviating the approach roads to the right close to the roundabout and then to the left at entry. Approach curves should be fairly gentle in order to ensure there is adequate forward visibility. Maycock and Hall (1984) found that a right hand bend leading to left hand entry deflection is safer than a gentle left hand bend.

The US guidelines state that roundabouts should be located such that the centre lines of all approaches pass through the centre point, for optimum visibility of the central island. If this is not possible, any slight offset should be to the left.

The UK, Norway and Australian guidelines suggest that entries may be staggered to increase deflection (Figure 26).

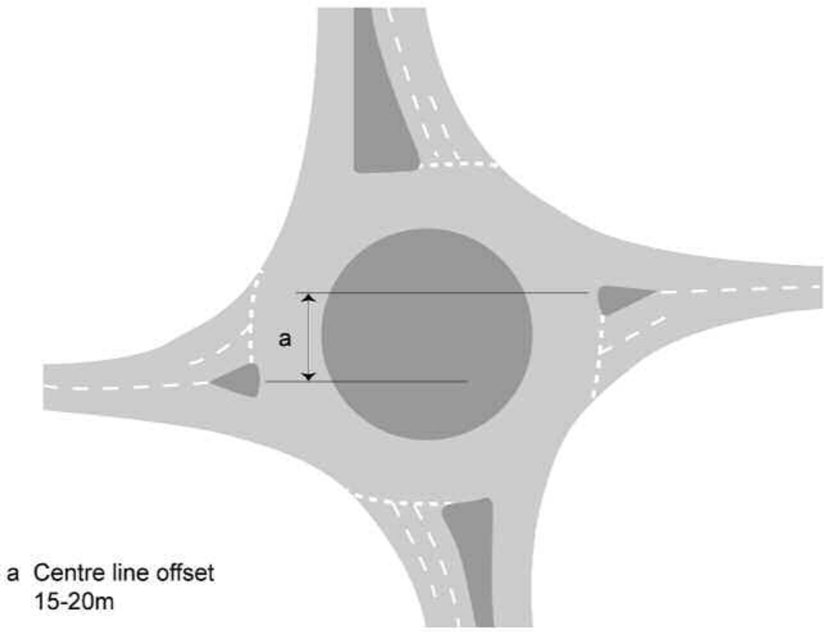


Figure 26: Staggering of arms to increase deflection

3.4 Provision for pedal cyclists

The various forms of provision for pedal cyclists are:

- Mix with traffic (no special provision, cyclist mixes with other vehicles)
- With-traffic cycle lane on circulatory carriageway (1.5 to 2m wide, often coloured)
  - With / without priority for cyclists
  - With / without separation kerb
- Cycle path round outside of roundabout (rather than on the circulatory carriageway) or a
  - With / without priority for cyclists
- Separate route for cyclists

An example of a Dutch roundabout with a cycle path is shown in Figure 27.

Figure 27: Single–lane roundabout in Enschede, Holland, with separate cycle path (photo from ELTIS website)

Provision for cyclists in the UK is fairly rare, with a few exceptions (see e.g. Layfield and Maycock, 1986, Lawton et al, 2003). It is generally recommended in guidelines for countries other than the UK that cyclists should mix with traffic where overall traffic is light; at busier roundabouts, a cycle path should be provided round the outside of the roundabout with cycle crossings or combined pedestrian/cycle crossings. In most countries, cyclists give way to motorised traffic at cycle crossings. The alternative, in which cyclists have priority, is used on some urban roundabouts in the Netherlands and in Sweden, but is regarded as being less safe. Even where cycle paths are provided, some cyclists may continue to mix with the traffic because of the delay involved in the use of a cycle path, as shown in Figure 28.

Figure 28: Cautious cyclist on cycle path at roundabout in France whilst experienced cyclist mixes with traffic at same roundabout

Various authors (Brilon, 1996, in Germany, Brüde and Larsson, 1999 in Sweden, and Botma, 1997, Minnen and Braimaister, 1994, and Weijermars, 2001, in the Netherlands) found that a cycle lane on the circulatory carriageway itself (Figure 29) was associated with more accidents than those in which cycles mixed with other traffic or had a separate cycle path, probably because this layout puts cyclists directly in the path of entering traffic and it results in cyclists not being in the direct line of sight of entering drivers. This concern was addressed at a UK roundabout in York by moving the cycle lane closer to the central island. However, although this approach is promising, there is not enough evidence to be sure whether or not it works. There was a reduction in accidents when the roundabout was introduced, but the comparison was with a priority intersection. Even where cycle paths are provided, some cyclists may continue to mix with the traffic because of the delay involved in the use of a cycle path.

Figure 29: Roundabout with cycle lane on circulatory carriageway (continental Europe)

Where cycle paths are used, it is generally agreed that cyclists should give way to motorized traffic at the crossings. Where this is not the case, e.g. at some urban roundabouts in the Netherlands, Finland and Sweden, it is recommended that the cycle crossings are only used in one direction (the direction of travel on the roundabout) when motorists must give way to cyclists. Conflict observations in Finland, where driving is on the right (Räsänen and Summala, 2000), showed that motorists turning right onto the roundabout frequently failed to see cyclists approaching from the right.

Both Alphand et al. (1991A) for French roundabouts and Brüde and Larsson (1996) for Swedish, Danish and Dutch ones found that single-lane small roundabouts are safest for pedal cyclists. Brüde and Larsson (1996) also found that mixing with traffic was satisfactory at low flow roundabouts, while a cycle path was the best option at busier roundabouts.

The concern that motorists would not see a cyclist using a cycle lane on the outer edge of the carriageway has been addressed for the UK Heworth Green roundabout in York by moving the cycle lane closer to the central island (Figure 30). This roundabout has two additional features

- Advanced give way lines for cyclists
- Cycle lanes that split into an exiting lane and a circulating lane

However, although this approach is promising, there is not enough evidence to be sure whether or not it works. There was a reduction in accidents when the roundabout was introduced, but the comparison is with a priority junction.

Figure 30: Roundabout at Heworth Green (photograph from York City Council) showing green cycle lanes in advance of the give way line and on circulatory carriageway away from periphery

In the American guidelines, cycle lanes are terminated on the approach to the roundabout and cyclists mix with other traffic. The Australian guidelines recommend the use of cycle paths where special provision is deemed to be required.

Pedal cycle facilities are not mentioned in the Norwegian guidelines studied (see Appendices A4 and A5), possibly because the guidelines were only a summary. Separate cycle paths with cycle crossings are the most common form of provision for cyclists in Sweden.

Conclusions: Cyclists should mix with traffic at urban roundabouts with low flow. External cycle paths are the best facility at larger urban roundabouts. Cycle lanes should not be permitted on the circulatory carriageway.

3.5 Pedestrian facilities

Pedestrian facilities at roundabouts fall into the following categories:

- Dropped kerb (with central refuge)
- Zebra crossing
- Signal controlled crossing
- Subway or footbridge

3.5.1 Uncontrolled (Zebra) crossings

In many countries, urban roundabouts have Zebra crossings on all arms, often adjacent to a cycle path. Recommended values for the distance of Zebra crossings from the edge of the circulatory carriageway are between 1 and 3 car lengths (Table 11). It should be noted that where arms are radial, the measurement of the crossing location is straightforward. However, it needs to be defined for UK roundabouts. A suitable definition is to measure along the kerb from the point at the end of the give way line to the edge of the studs closest to the roundabout.

In the UK, the provision of Zebra crossings at roundabouts is relatively rare and they are often sited on only one or two arms. No specific distance is quoted in TD 16/93, but they should be beyond any flare (typically 5m in urban areas). Where there is a need for an adjacent cycle path, a Toucan crossing is used rather than a Zebra (see Section 3.5.2).

Cycle paths in the UK commonly have a signal-controlled Toucan crossing for both cyclists and pedestrians rather than an uncontrolled crossing.

Recommended values in other countries for the distance of uncontrolled crossings from the edge of the circulatory carriageway are between 1 and 3 car lengths.

Table 11: Distance of Zebra crossing from give way line

	Single lane		Double lane	
Country	**Min (m)**	**Max (m)**	**Min (m)**	**Max (m)**
Australia	6	12	6	12
France	2	5	2	5
Germany	-	-	5	6
Netherlands	5	5	5	5
Norway	5	12	10	12
USA	7.5	7.5	7.5	22.5

3.5.2 Signal-controlled crossings

Countries other than the UK mostly do not appear to use signal controlled crossings at roundabouts. An exception is France at double lane roundabouts, where they must be sited at least 15m from the give way line. One possible reason for the lack of use may be the potential confusion over the form of junction control. Local Transport Note 2/95 states that a Zebra crossing is preferred for just this reason. However, for a sample of roundabouts in Nottingham, Thomas, Lloyd and Gallear (1990) found that the presence of a Pelican crossing did not affect accidents between entering and circulating vehicles and concluded that there was no evidence that Pelican crossings were confused with signalised roundabouts.

Harper (PTRC, 1985) found a reduction in accident frequency when Pelican crossings were used to replace Zebra crossings in Swindon. He also found that the accident frequency was lower at Pelican crossings near roundabouts than at those elsewhere, possibly again due to lower speeds and greater alertness on the approach to roundabouts.

TD 16/93 recommends that signal-controlled crossings are sited sufficiently far back to prevent “entry starvation” i.e. the entry capacity on the roundabout arm being limited by the capacity of the crossing (Hunt and Jabbar, 1995). They point out that this displacement potentially increases geometric delay (journey time) for pedestrians: if facilities do not then coincide with the routes pedestrians may to take (“desire lines”), this may lead to risky behaviour as pedestrians try to minimise the time required wish to negotiate the roundabout. For example, a displacement of 21m allows storage for 3 vehicles per lane but increases pedestrian journey time by 35 seconds (at a walking speed of 1.2m/s).

Signal-controlled crossings should not be placed between 20m and 65m from the give way line, since it is recognised that beyond 65m, the crossing is separate from the junction; up to 20m, speeds are still low (Rainbird, 2003). There needs to be a balance between the flared geometric design, which tends to push the crossing location away from the merge roundabout, and the increasing speed of vehicles as they leave the roundabout, pulling it nearer to the roundabout (Middleton, 2004).

LTN 2/95 states that if a signal-controlled crossing is provided, it should preferably be staggered, with the entry side closer to the roundabout than the exit side, in order to avoid traffic queuing back on to the roundabout.

The combination of this advice suggests that signalised crossings should be sited at about 20m (or well away from the roundabout). The use of Puffin crossings rather than Pelicans will ensure that drivers are stopped only when necessary. If there is a high pedestrian flow and signalised crossings are used on more than one arm, there may be a case for signalisation of the entire roundabout.

Conclusion: Where traffic flow is low, a dropped kerb is adequate. At medium flows, where there is a substantial pedestrian demand, use a crossing close to the roundabout (but upstream of any flaring). If signal-controlled, the crossing should be either at 20m or at least 60m from the give way line to avoid confusion with the roundabout itself and minimize queueing back onto the roundabout.

3.6 Visibility requirements

3.6.1 Approach visibility

The UK Standard requires the desirable minimum stopping sight distance as given in TD 9/93 to allow drivers to judge the required braking distance for the layout ahead. The West Midlands Region Road Safety Audit Forum (1997) states that it is not good practice to site roundabouts on the top of hills or hidden round bends because of the potential problems with overshoots.

3.6.2 Visibility to the right

Similarly, the UK standard requires that at 15m back from the give way line drivers should be able to see the full width of the circulatory carriageway to their right for a distance appropriate to the stopping sight distance for the circulatory traffic. Figures 31 and 32 show the visibility required to the right on entry and at 15m from the give-way line.

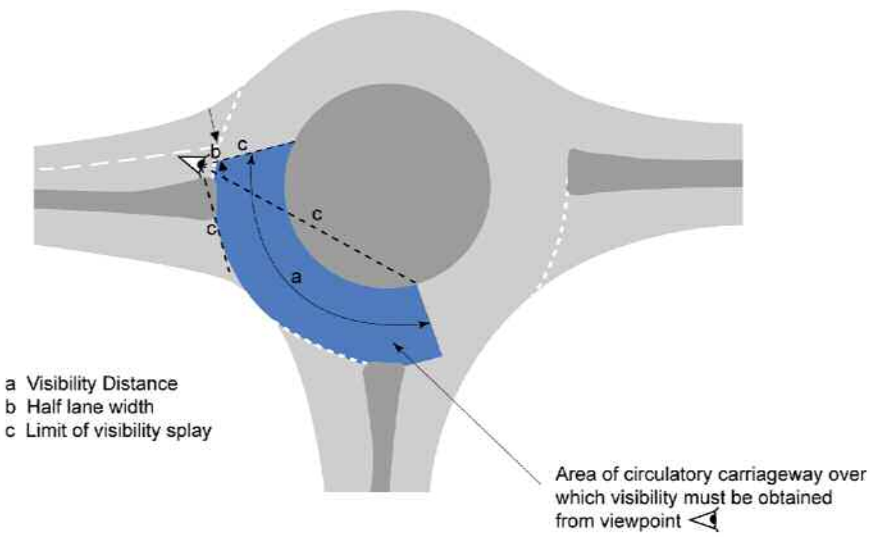


Fig 31: Visibility to right required at entry

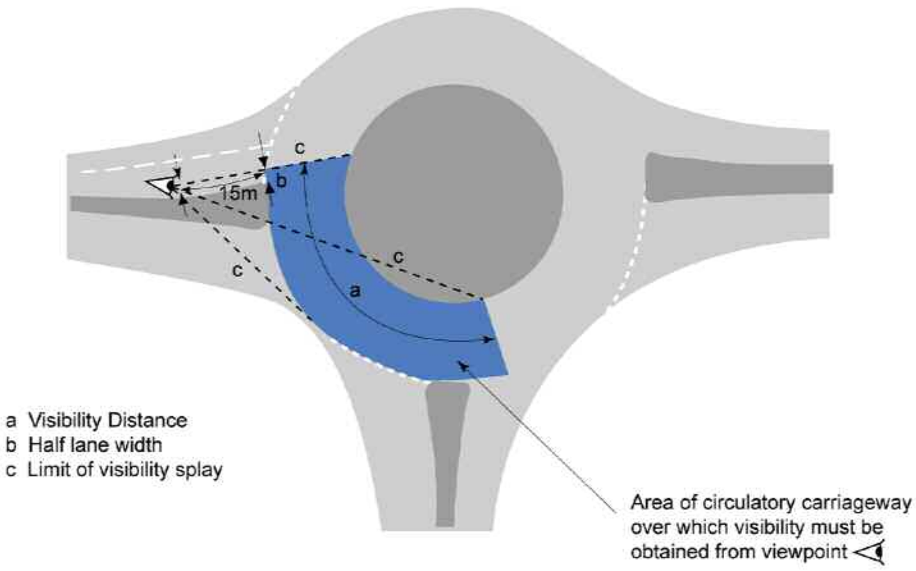


Fig 32: Visibility to right required at 15m back from give way line

The West Midlands Region Road Safety Audit Forum (1997) suggested that providing suitable visibility to the right when the vehicle is more than 15m in advance of the give way line could increase the likelihood of the driver making the decision to continue through the roundabout too early, misjudging the speed on the circulatory carriageway, or failing to see a two-wheeler (see also Davies et al, 1997).

Conclusion: On dual carriageway approaches to roundabouts (or single carriageways with a long splitter island), planting or other screening can be used on the median to limit the visibility to the right until the driver is within 15m of the give way line, in order to minimise the danger of drivers over-shooting the give way line.

3.6.3 Forward visibility at entry

Forward visibility must enable drivers to see the full width of the circulatory carriageway for a distance depending on the inscribed circle diameter (the whole junction for diameters of less than 40m). This is illustrated in Figure 33.

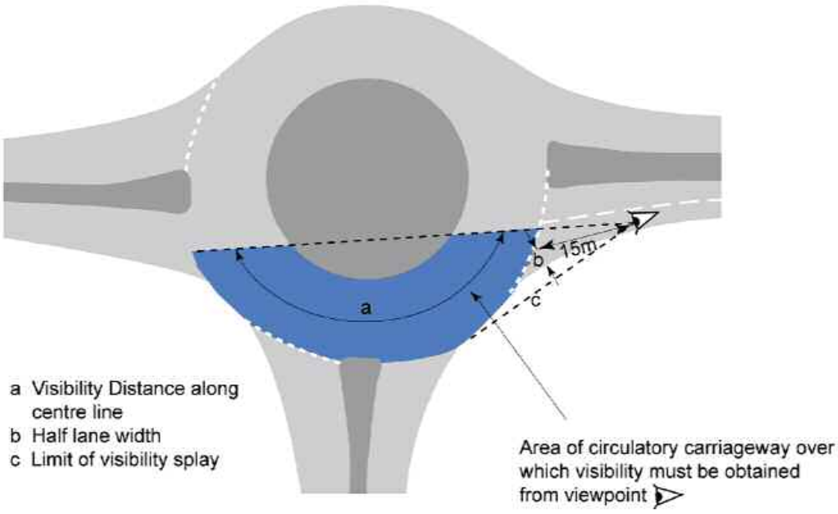


Fig 33: Forward visibility required at entry

Guidelines in Germany, France, the Netherlands, USA, and Australia recommend the obstruction of the forward visibility by the central island, at the same time ensuring that the outer area of the central island is free from obstacles, so that circulating vehicles can still be seen.

3.6.4 Circulatory visibility

For sight distance while travelling on the circulatory carriageway, guidelines in Germany, France, the Netherlands, USA and Australia recommend that the first quarter to the left (right for countries driving on the right) can be seen. The UK Standard requires a stopping sight distance on the circulatory carriageway depending on the inscribed circle diameter, varying from the whole junction if the inscribed circle diameter is less than 40m to 70m if the inscribed circle diameter exceeds 100m (see Figure 34). Circulatory visibility is affected by planting or objects on the central island and it is therefore important to leave a space round the edge of the central island that has at most low planting.

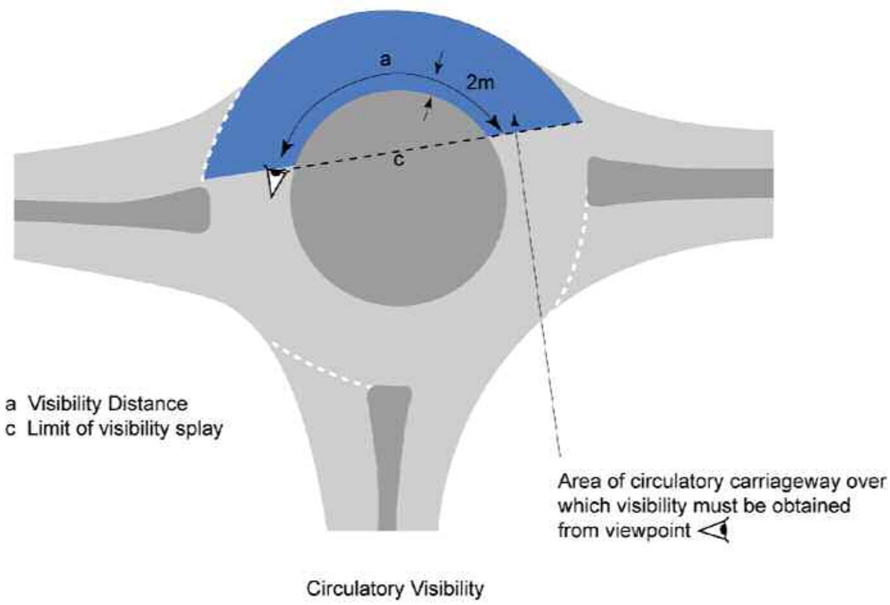


Fig 34: Circulatory visibility

3.6.5 Exit visibility

There is no requirement in TD 16/93 on visibility for vehicles exiting the roundabout, although TD 9/93 (DMRB 6.1.1) should apply once traffic has fully turned. TD 50/04 (DMRB 6.2.3) shows junction inter-visibility zones across stoplines but this is intended mainly for pedestrians. The West Midlands Region Safety Audit Team suggests that adopting a desirable minimum stopping sight distance of 90m may be appropriate 'up to the border of the inscribed circle diameter'. Another possibility is to assume a design speed of 50km/h (30mph) on the circulatory carriageway, in line with the 100m maximum entry path radius and use the associated distance from TD 9, namely 70m.

Conclusion: the exit visibility should be consistent with the requirements for stopping sight distance on the circulatory carriageway until the vehicle crosses the inscribed circle diameter after which TD 9 should apply.

3.6.6 Pedestrian crossing visibility

In TD 16/93, it is a requirement that:

- Drivers approaching a pedestrian crossing should have a minimum stopping sight distance corresponding to the design speed of the link)
- At the give way line, drivers should be able to see the full width of a pedestrian crossing across the next exit if the crossing is within 50m of the roundabout (see Figure 35).

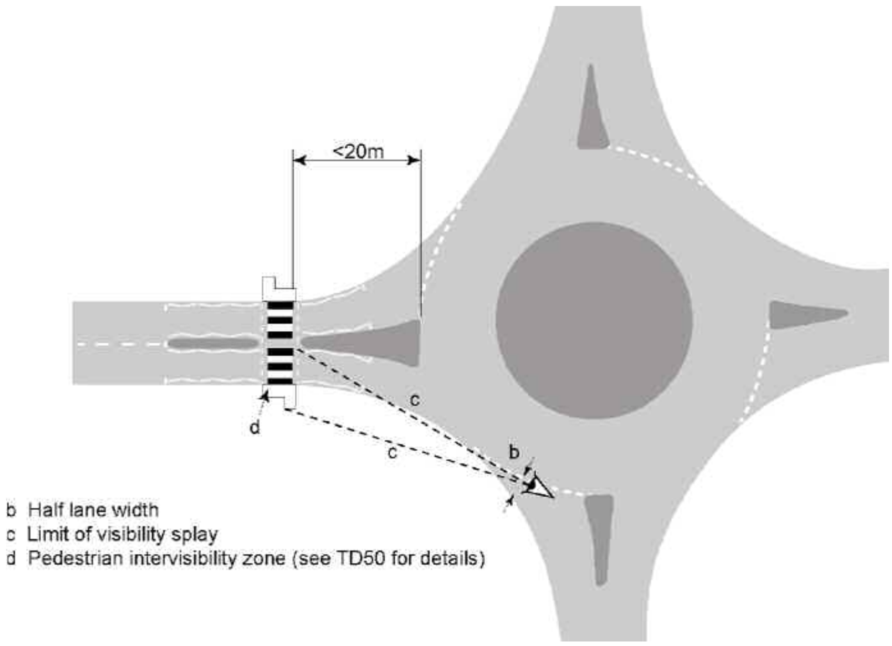


Figure 35: Visibility on entry to roundabout to pedestrian crossing at next exit (within 50m)

3.7 Landscaping

Vegetation can be used to improve the aesthetic qualities of a roundabout. However, it can lead to maintenance issues and the outer part of the central island at least needs to be kept clear in order to avoid restricting visibility (see section 3.6.5 and e.g. Safety Auditor's Perspective – New Zealand). The French guidelines recommend keeping the outer 2m clear. In TD 16/93, it is recommended that islands with a diameter of 10m or less are not planted.

3.8 Signing and marking

3.8.1 Road markings

In the UK, road markings at roundabouts are part of a separate Standard (DMRB 6.2.3 TA 78/97). This states that arrow markings at the give way line are generally used only if there is uneven approach queueing for example due to a dominant straight ahead or right turn movement. A right turn arrow in the offside lane can be confusing, particularly for drivers from countries other than the UK.

Destination markings are sometimes used on the approach and circulatory carriageway. West Midlands Region Road Safety Audit Forum (1997) recommends abbreviated place names rather than road numbers, except for motorways.

Lane markings on the circulatory carriageway are used mainly at large roundabouts and may be concentric, partially concentric or spiral. They are used on signalised and partially signalised roundabouts and gyratory systems.

In overseas guidelines, double lane roundabouts often have concentric markings. Despite not being recommended in the French guidelines, they are used on some roundabouts.

3.8.2 Chevron markings on the central island

Worthington (1992) reported that the use of reflective block-paved chevrons on the central island of a roundabout (see Figure 36), in conjunction with lighting to full standards:

- enhanced roundabout conspicuity during both night and day time conditions
- reduced approach speeds
- reduced accidents involving vehicles overrunning the central island and related damage to traffic signs

Chevrons are now common in the UK.

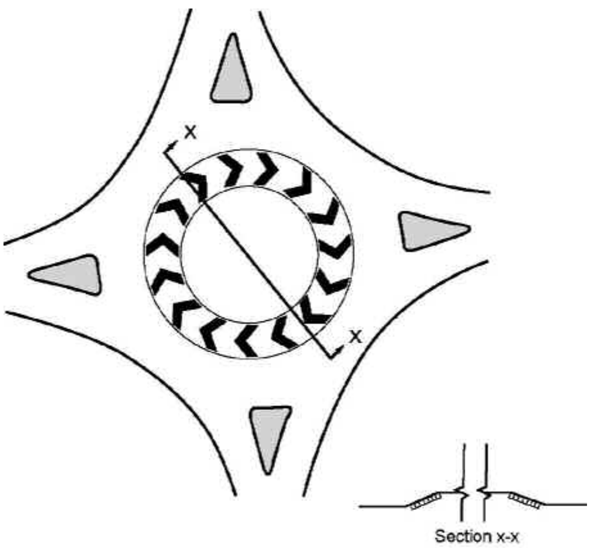


Figure 36: Chevron markings

3.8.3 Signing

Signing at UK roundabouts is dealt with in the Traffic Signs Manual and has the following main elements:

- A map type advance direction sign
- A flag type direction sign on each exit, usually on the deflection island

- Keep left bollards
- Left turn sign with chevron markings sited on the central island (sometimes emphasized by a ring of chevrons)
- A triangular “roundabout” warning sign with “reduce speed now” plate on high standard roads

3.9 Lighting

Lighting is commonly used at roundabouts because the central island presents an obstacle to traffic and there is therefore a need to see the junction at the required visibility distance, which is not possible with headlights alone on high speed roads (Jacoby and Pollard, 1995).

Lighting at the roundabout should be different from that on the approaches to aid drivers’ awareness of the junction. There is a need to consider alignment and vegetation. Peripheral lighting with columns placed symmetrically round the roundabout is preferred in most countries, since at large roundabouts, a central light column would have to be very tall to illuminate the whole of circulatory carriageway, which could waste energy and be environmentally intrusive. By contrast, the Australian guidelines suggest the use of a central mast at the island centre at small roundabouts.

Lighting columns need to be placed where there is little risk of their being hit e.g. well back from the circulatory carriageway. The Australian guidelines suggest avoiding their location on small deflection islands.

Lighting in the UK should be to British standards BS5849 Parts 4 (at-grade roundabouts) and 5 (grade-separated roundabouts). BS 5489 Part 4 recommends lighting for at least 60m along exit roads, but approach lighting may detract from roundabout conspicuity.

In some circumstances, there is a potential conflict between lighting and environmental considerations. Trials were undertaken for the Highways Agency of environmentally friendly low impact lighting on one quarter of the Crosthwaite roundabout on the A66 in Cumbria. Guidance lighting is provided by coloured ground-mounted light emitting diode (LED) clusters in the form of road studs, intended to outline the road boundaries i.e. the nearside kerb edge, the central island and the deflection islands. The effect on safety has not yet been evaluated. Another trial at the A616 Flouch roundabout in Derbyshire, suggested that, subject to monitoring of accidents, reduced levels of light may be adequate at rural roundabouts.

Conclusions: Roundabouts should normally be lit; LED lighting should be considered in environmentally sensitive areas.

3.10 Skidding resistance

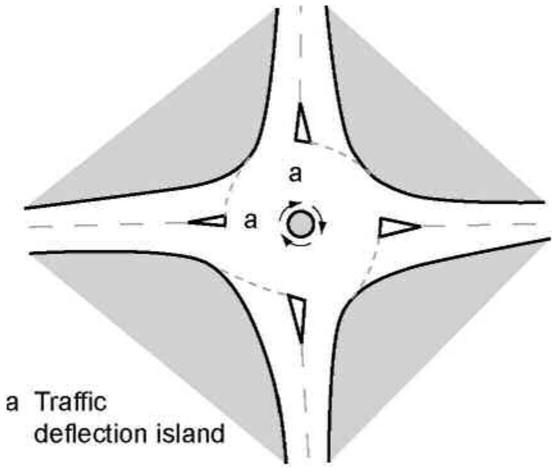
A high value of skid resistance is required on the approach to roundabouts if the 85th percentile speed is greater than 90km/h. On the circulatory carriageway, because speeds are lower, skidding resistance is derived from the micro-texture, that is, the surface of the aggregates that form the road. West Midlands Region Road Safety Audit Forum (1997) points out that it is important to maintain skidding resistance in wet conditions at roundabouts, especially on the approaches where heavy braking occurs.

3.11 Urban mini-roundabouts

The information on mini-roundabouts is included for completeness.

3.11.1 Number of arms at mini-roundabouts

Mini-roundabouts generally have 3 or 4 arms, but in the UK, they occasionally have up to five arms where they are used to replace another junction type. In this case, one or more of the arms may be very lightly trafficked or an access rather than a public road. Typical 4-arm mini-roundabouts are shown in Figures 37 and 38.



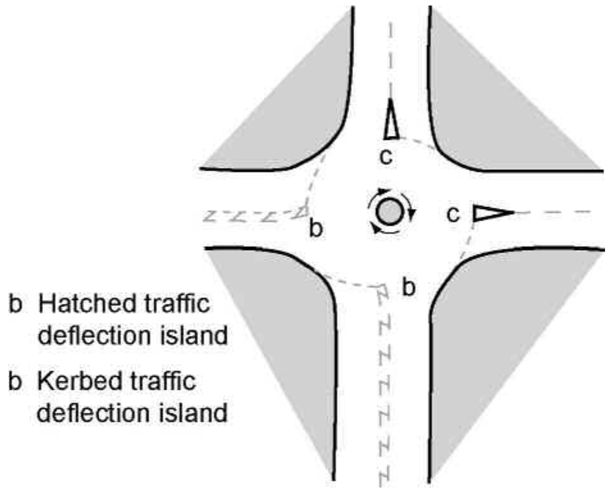


Fig 37: Mini-roundabout with flaring **Fig 38: Mini-roundabout without flaring**

3.11.2 Inscribed circle diameter at mini-roundabouts

The recommended values for inscribed circle diameters at mini-roundabouts in the guidelines studied ranged from a minimum of 10m to a maximum of 28m (Table 12).

Table 12: Inscribed circle diameter

	Min (m)	Max (m)
UK	-	28
France	15	24
Netherlands	10	20
Norway	-	25
Sweden	-	28
USA	13	25

3.11.3 Central island of mini-roundabout

The recommended diameter and height of the central island in TD 16/93 for mini-roundabouts (from 1 to 4m and maximum 125mm respectively) are comparable with those in other countries (Table 13). Sawers (1996) advocates a maximum of 6m. The island is generally constructed of white thermoplastic and may be domed. Some mini-roundabouts have islands with a low kerb or are constructed of granite setts.

Table 13: Central island dimensions at mini-roundabouts

	Diameter		Height	
	Min (m)	Max (m)	Min (m)	Max (m)
UK	1	4	0	0.125
France	1.5	2.5	0.1	0.15
Netherlands	-	-	0.1	0.14
Norway	1.5	4	-	-
Sweden	-	4	-	-
USA	4	calculated	-	0.125

3.11.4 Crossfall at mini-roundabouts

Crossfall often follows the road on which the mini-roundabout is constructed. In the UK, either inward or outward crossfall may be used. Other countries use outward crossfall of between 1.5 and 3%.

3.11.5 Entry width at mini-roundabouts

The recommended entry width for mini-roundabouts in the UK (≥2.50m per lane) is comparable with that in other countries (Table 14). In contrast to the guidelines in other countries, TD 16/93 allows flared entries on mini-roundabouts, although they are much less common than on normal roundabouts.

Table 14: Entry and exit widths at mini-roundabouts

	Entry width		Exit width	
	Min (m)	Max (m)	Min (m)	Max (m)
UK	2.5	-	-	-
France	2.5	3.5	2.75	3.5
Sweden	3.5	-		

3.11.6 Provision for pedal cyclists

Pedal cyclists generally mix with traffic on mini-roundabouts, although a cycle lane is occasionally used.

3.11.7 Pedestrians at mini-roundabouts

Both Zebra and Pelican crossings are used at mini-roundabouts in the UK.

4 Accident analysis

4.1 Introduction

All countries have found roundabouts to be a relatively safe form of junction. The reasons for their low accident rate were summarised in NCHRP Synthesis 264 (1998) as:

- Reduced speeds / increased awareness because of need to deflect from ahead path
- Low number of conflict points at a roundabout compared with other junction types
- Separation of conflict points
- One-way operation of circulatory carriageway

However, it is noted that other countries claim a better safety record for their roundabouts than the UK. Possible reasons for differences in the safety record are as follows:

- Higher flows at UK roundabouts
- Difference in definition of junction accident. For example, the distance at which an accident is treated as non-junction is 20m from the give way line in the UK, but 50m at urban junctions and 100m (150m if there is an acceleration lane) at rural junctions in France (MVA, 2004). In the UK, a 20m distance also applies on the exit from the roundabout, but no distance is given for the exit in the French guidelines
- Differences in the definition of injury accidents:

  fatal – e.g. death occurs within 6 days in France (30 days in the UK)

  serious – e.g. more than 6 days in hospital in France (kept in hospital in the UK)

  slight – e.g. receives hospital treatment in France (taken to hospital / reports injury in the UK)
- Cultural differences, for example, overseas drivers may be more cautious because they are still relatively unfamiliar with roundabouts and are unsure about the priority rule
- Other countries mostly use single lane roundabouts
- The main UK study (Maycock and Hall, 1984) is old (based on data from 1974 to 1979). It is likely that improved roundabout design as a result of their work, reductions in two-wheeled traffic over the past 25 years, together with improved vehicle safety will have reduced accident rates

Because of the differences in driver behaviour, in accident reporting, and in sampling, it should be pointed out that the international comparison of accident frequencies and rates in the following sections needs to be treated with caution and is included for completeness. In addition to this comparison, the report considers the effect of individual design elements on accident groups. As for all junction types, the biggest effect on accident frequency at roundabouts comes from traffic flow. However, the effect of geometric design can also be considerable.

4.2 Conversion from other junction types

In most countries, ‘before-and-after’ studies have been undertaken to show the effect on safety of conversion from another junction type to a roundabout. Large reductions in all types of accidents have been demonstrated (although part of the reduction may be due to site selection bias – see e.g. Hauer, 1997). The accident groups showing the smallest reductions are those involving two-wheelers.

For example, Schoon and Van Minnen (1994) in the Netherlands studied 181 junctions converted to roundabouts. The mean reduction was 51%, from 1.3 casualties per year (over 5.3 years) to 0.37 casualties per year (over 2 years), with the greatest values being for cars (63%) and pedestrians (73%). Cyclists had the smallest reduction (6%).

A study in France in which injury accidents were reduced by 78% from 1.42 per year to 0.31 per year is reported in NCHRP Synthesis 164 (1998). In the US, a mean accident reduction of 51% at 11 sites is reported in FHA (2000) following conversion to a roundabout. In Australia, the casualty accident rate decreased by 74% after roundabout installation (Arndt and Troutbeck, 1995) and by between 45 and 87% in another study by Wadhwa (2003).

4.3 Accident frequency and severity

An accident study undertaken in conjunction with the current research determined the accident frequencies by severity over a five year period (see Table 15 and Appendix B) for a sample of 1162 roundabouts. The sample comprised all roundabouts in some local authorities, but only the busier roundabouts from a few others, making the sample slightly biased towards busier roundabouts.

Table 15: Average accident frequency at UK roundabouts by number of arms 1999 to 2003 (current study)

No. of arms	No. of sites	Accident frequency				Severity (% fatal and serious)
		Single cway roads	Dual cway roads	Grade separated junctions	All roads	
3	326	0.63	1.28	2.70	0.79	9.3
4	649	1.08	2.65	5.35	1.79	7.1
5	157	1.72	3.80	7.67	3.66	7.1
6	30	2.11	4.62	8.71	5.95	5.2
All	1162	1.00	2.60	6.28	1.87	7.2

Table 15 shows an increase in accident frequency with road type, which serves as a proxy for flow.

As might be expected, there is a clear increase in accident frequency with number of arms (Figure 39). A similar result is reported in NCHRP Synthesis 164 (1998) for a French study in which accident frequency increases with inscribed circle diameter. It is in line with the manner in which the number of conflict points increases with the number of arms.

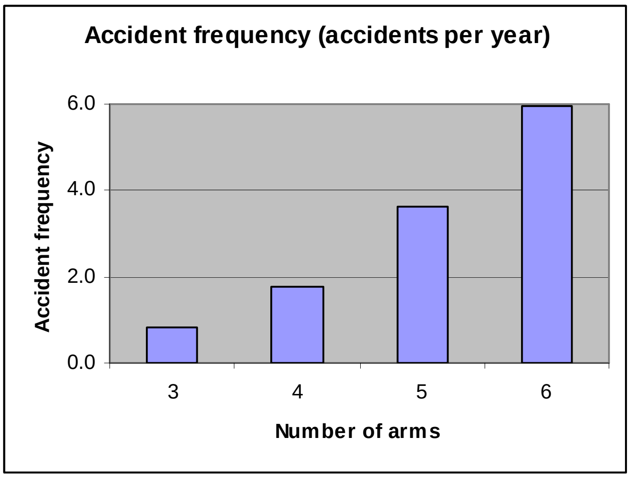


Figure 39: Accident frequency as a function of the number of arms

The accident frequency of 1.79 for 4-arm roundabouts is much lower than that of 3.31 obtained by Maycock and Hall (1984) – Table 16. In part, the difference may be attributed to improvements in general safety and in roundabout design over the 25 year period since data was collected for the earlier study. The Maycock and Hall sample was biased so as to include a disproportionate number of sites with a high flow and contained a number of poorly designed roundabouts with very little entry deflection. The present study found that accident frequency at 4-arm roundabouts was lower on single-carriageway roads (1.08), but higher on dual-carriageway roads (2.58) and at grade-separated junctions (5.34).

Mean values of accident frequency are available for a number of different countries. It should be noted that the results obtained are very dependent on the sample of roundabouts chosen, the traffic flows (often not measured, and the percentages of different road user types. Table 16 compares the mean accident frequency for samples of roundabouts in different countries.

The accident frequencies traced for roundabouts in other countries should probably be compared with the recent UK average value for 4-arm roundabouts on single carriageways (1.08 accidents per year), although it must be remembered that the UK value is for roundabouts with one lane flaring to two lanes on entry while most of the other values are for single lane roundabouts. Guichet (1997) reported a frequency of 0.11 per year for French roundabouts, but more recently (2005) gave a figure of 0.05 based on approximately 27,000 roundabouts. Arndt and Troutbeck (1995) predicted a value of 1 accident per arm per year for a typical double lane roundabout in an urban environment in Australia, but this included some damage-only accidents. Harper and Dunn (2003) obtained average values of 0.42 accidents per year for single lane roundabouts and 0.79 for double lane roundabouts in New Zealand.

Accident severity (percentage of accidents that are fatal or serious) is low, with only 7% in the current UK study, much lower than the value of 16% in Maycock and Hall (1984). This difference is likely to be due to improvements in vehicle and roundabout safety.

Table 16: Accident frequency and severity at roundabouts in different countries

Country	Reference	No. of roundabouts in study	Accident frequency	Severity (% fatal and serious)
Australia	Quoted in NCHRP 264 (1998)	290	0.6	-
Australia[1]	Arndt and Troutbeck (1995)	-	4	-
Belgium	Antoine (2005):			
	Rural	49	0.55	32
	Suburbs	59	0.93	24
	Urban	43	0.85	16
Denmark	Jorgensen (1990)	63	1.0 to 1.25	-
France	Guichet (1997)	12,000	0.11	25 to 38
France	Guichet (2005)	27,000	0.05	-
New Zealand	Harper and Dunn (2003)	95	0.51	12
Netherlands[2]	Schoon and Van Minnen (1994)	16	0.75	-
Netherlands[2]	Van Minnen (1993)	46	0.23	-
Switzerland[3]	Spacek (2004)	32	0.85	22 to 42
UK	Maycock and Hall (1984)	84	2.36 to 4.38	16
UK	Current	1,162	1.77	7
US	NCHRP Synthesis 264 (1998)	11	1.5	-

1 Estimated for double lane roundabouts; includes property damage only accidents

2 Casualties per roundabout per year

3 Estimated

4 Single lane roundabouts in Maryland and Florida

Table 17 (see also Table B9) shows the percentage of accidents involved by type of road user involved and their severity. Both motorcycles and pedal cycles, but particularly the former, are over-represented. The severity is much higher for motorcyclists and pedestrians than for other vehicle types.

Table 17: Accidents by type of vehicle involved (1999 to 2003)

	% of accidents	Severity
Pedal cycles	8%	10%
Motorcycles	14%	19%
Cars and taxis	77%	6%
Public Service Vehicles	36%	8%
Light goods vehicles	6%	6%
Heavy goods vehicles	9%	8%
Pedestrians	3%	23%

4.4 Accident rate

Accident rate is more useful than frequency as an indicator of safety because it takes account of traffic flow. However, this makes it more costly to measure and therefore fewer studies are undertaken and sample sizes tend to be smaller. It is usually defined as accidents per 100 million vehicles passing through the junction. Values from a number of different countries are shown in Table 18. They include only injury accidents except where otherwise stated.

The value from the earlier UK study (Maycock and Hall, 1984) varied from an average of 21 accidents per 100 million vehicles at large roundabouts to 37 accidents per 100 million vehicles at small roundabouts. It was not possible to obtain flows for most of the roundabouts in the current study; the mean accident rate obtained was based on a small number of sites with high mean accident frequency, and was also fairly high (36), based on a sample of 44 roundabouts, with flows ranging from 10,000 to 50,000 vehicles per day, and a mean value of 28,000.

Rates in Belgium averaged 14 accidents per 100 million vehicles entering the intersection. The mean accident rate at urban roundabouts in France was 4.5 per 100 million vehicles (Alphand et al, 1991A), much lower than the UK values. Swedish rates varied from very low to values similar to those for Belgium. In Germany, the accident rate given by Brilon (2005) ranged from 53 to 162 per 100 million vehicles, very much larger than other values as it includes damage-only accidents. The German rates are all for single lane roundabouts, with flows in the range 5,000 to 25,000 vehicles per day.

It is likely that the rates in European countries other than the UK were obtained mainly, if not exclusively, at single lane roundabouts.

Table 18: Accident rates at roundabouts in different countries

Country	Reference	No. of roundabouts	Accident rate (accidents per 100 million vehicles)	Mean total vehicle inflow (vehicles per day)
Australia[1]	Austroads (1993)	-	4 to 8	
Belgium	Antoine (2005):			
	Rural	49	14	10,000
	Suburbs	59	13	19,000
	Urban	43	14	17,000
Denmark	Jorgensen (1990)	25	14	
France	Alphand et al (1991A)	179	4.5	
Germany[1]	Brilon and Stuwe (1993)	-	124 to 658	
Germany[1]	Brilon (2005)	-	53 to 162	
Norway	Brown (1995)	-	5	
UK	Maycock and Hall (1984)	84	21 to 37	32,000
UK	Current (high flow)	44	36	28,000
Sweden	Brude and Larsson (1999)	182	1.8 to 16	
US	Quoted in Wadhwa (2003)[2]	11	8	

1 Includes property damage only accidents

2 Single lane roundabouts in Maryland and Florida

4.5 Accident modelling in the UK

In a major cross-sectional study of accidents at 4-arm roundabouts, Maycock and Hall (1984) developed accident predictive models based on vehicle and pedestrian flow and on geometry, using the technique of generalised linear modelling. A similar study was undertaken by Kennedy et al (1998) for mini-roundabouts. Models for both are now incorporated into ARCADY and *Safe*NET software (Binning, 2004, TRL, 1999).

The relationships took the form:

$$A = kQ^{\alpha} \quad (1)$$

where A is the number of accidents per year, Q is the flow function and k and α are parameters to be determined by the regression. Alternatively, two flow functions, each with different exponents can be used:

$$A = k\, Q_1^{\alpha}\, Q_2^{\beta} \quad (2)$$

where A could be the number of entering-circulating accidents on an arm and Q_1 and Q_2 could represent the entering and circulating flows respectively and k, α and β are parameters. These models were extended to allow the effect of geometric and layout variables to be determined:

$$A = k\, Q_1^{\alpha}\, Q_2^{\beta} \exp(\sum g_i\, G_i) \quad (3)$$

where the G_i are geometric variables and the g_i are parameters.

Depending on the flow function adopted, these models are applicable either to the whole junction or to each arm separately. The simplest models applied to the whole junction and used the cross product flow function Q_{CF} i.e. the product of total entering flows on one pair of opposite arms times the total entering flow on the other pair of opposite arms:

$$A = 0.062\, Q_{CF}^{0.68} \quad (4)$$

4.6 Accident modelling in France

A simple model that is linear in flow is used for total accidents in France:

$$A = 0.15 \times 10^{-4}\, Q$$

However, a model similar in form to Maycock and Hall (1984) is also used (Guichet, 1997)::

$$A = 0.24 \times 10^{-6}\, Q^{1.4}$$

where A is the accident frequency at the roundabout and Q is the total inflow.

4.7 Australian modelling approach

Arndt and Troutbeck (1995) developed models using multiple linear regression with independent variables related to driver behaviour rather than geometric design. These include flow, 85th percentile speed, vehicle path radius and changes in 85th percentile speed as the vehicle progresses through the roundabout. For example, their model for approaching rear end shunts is similar to (2) with an additional speed term:

$$A = c_1\, Q_1^{\alpha}\, Q_2^{\beta}\, S^{z} + c_2 \quad (4)$$

where c_1 and c_2 are constants and S is the 85^{th} percentile speed on the approach curve, whilst that for entering-circulating accidents is similar but takes into account the relative 85^{th} percentile speeds on the approach curve and the circulatory carriageway. The model for single vehicle accidents also takes into account changes in speed at the start of each geometric “element”. Arndt and Troutbeck’s models were later refined to include variables such as the number of approach lanes, the vehicle path radius on each geometric element and the length of the driver path on this element. The revised models are described in the Queensland Road Planning and Design Manual, Chapter 14 (2002), including a speed prediction model, and have been incorporated into the Arndt software.

4.8 Swedish modelling approach

Brude and Larsson (1999) developed simple models for collision and injury accident rates (accidents per million vehicles entering the junction).

$$\text{Collision rate} = 0.1353 \times 0.86^{3arm} \times 1.88^{speed70} \times 1.20^{2lanes}$$

where the dummy variables represent the number of arms (3arm= 1 if there are 3 arms, 0 with 4 arms), the maximum local speed limit (speed70= 1 if the maximum local speed limit is 70km/h, 0 if 50km/h) and the number of entry lanes (2lanes= 1 if there are 2 entry lanes, 0 with 1 entry lane).

The injury accident rate is given by:

$$A = 0.8178 \text{ x (collision rate)}^{1.6871}$$

An alternative model predicts that the accident rate increases by about 40% if the speed limit within 600m of the roundabout is higher than the local speed limit.

4.9 Accident groups

The main accident groups identified in the Maycock and Hall study were:

- *entering-circulating accidents* in which an entering vehicle collides with a vehicle already on the roundabout
- *approaching accidents* i.e. rear shunts and lane-changing accidents on the approach
- *single vehicle accidents* involving a vehicle colliding with some part of the junction layout or with street furniture
- *'other' vehicle accidents* including circulating vehicles colliding with each other, circulating vehicles colliding with vehicles exiting the junction, exiting vehicles colliding with entering vehicles and with other exiting vehicles and a few other miscellaneous accidents
- *pedestrian accidents* in which a pedestrian is hit by a vehicle

Some of the above categories are split in other countries e.g. failure to give way on entry, single vehicle accidents on the approach, rollover accidents, single vehicle collision with central island, rear shunts on exit, accidents involving two circulating vehicles etc. Accidents involving cyclists are also often treated separately.

The proportion of accidents in each group depended on the type of roundabout. Small island roundabouts (not mini-roundabouts) had a much higher proportion of entering-circulating accidents (71% compared with 20%), whilst conventional and dual-carriageway roundabouts had much higher proportions of single vehicle and approaching accidents. There were very few pedestrian accidents even at urban roundabouts.

The most important geometric variables found to affect accidents were:

- *Entry path curvature* (deflection of the vehicle path on entering the roundabout) is an important determinant of accidents; increasing deflection had the effect of reducing entering-circulating accidents, but increasing approaching accidents and single vehicle accidents. *Entry path radius* is the inverse of entry path curvature
- *Entry width* has the effect of increasing entering-circulating accidents but reducing approaching accidents; the entering-circulating effect is generally more important
- *Ratio factor* is a function of the ratio of the inscribed circle diameter to the central island diameter; it was used mainly to distinguish between conventional and small roundabouts
- *Proportion of motorcycles in the flow* has the effect of increasing entering-circulating accidents; the proportion of pedal cycles was not found to be statistically significant despite the fact that pedal cycles are also at risk.

Other variables found to have an effect on accidents were:

- *Angle with next arm* measured between the centre lines
- *Approach width* indicates the amount of flaring on the arm when compared with the entry width
- *Approach curvature* is the inverse of the radius of the bend in the road on the approach to the roundabout

Table 18 compares the percentage of accidents by accident group at French and UK roundabouts. There were notably more approaching accidents and fewer single vehicle and entering-circulating accidents at the UK roundabouts. In the current study, however, only 14% of the total were single vehicle accidents.

Table 18: Percentage of accidents by accident group at roundabouts in various countries

% of total	Single vehicle accidents	Approaching accidents	Entering-circulating accidents	'Other' vehicle accidents	Pedestrian accidents
Australia – Arndt and Troutbeck (1995)[1]	18	22	51	9	
France – Guichet (1997)	28	7	37	15	10
Germany[1] – Brilon and Stuwe (1993)	28	17	30		
New Zealand – Harper and Dunn (2003)	19	21	45	15	
Switzerland – Spacek (2004)	16	10	59	15	
UK – Maycock and Hall (1984) – conventional and dual-carriageway	30	25	20	18	6
Small island	8	7	71	10	4

1 Includes property damage only accidents

4.9.1 Single vehicle accidents

Maycock and Hall (1984) found that at 4-arm roundabouts in the UK, the risk of single vehicle accidents increased with wider entries and with greater entry path curvature, but decreased where there was greater approach curvature. The latter has the effect of reducing the approach speed for vehicles. If the entry speed is too great, then vehicles will not be able to negotiate the roundabout safely. Maycock and Hall also found that greater sight distance to the right (left in countries that drive on the right) was associated with an increase in single vehicle accidents, although this variable was not used in their preferred models.

There is anecdotal evidence that single vehicle accidents are more frequent where:

- there is poor delineation of the roundabout approach
- there are high speeds on the approach and the median line does not lie on an arc that is tangential to the central island

In an evaluation of the effect of geometric parameters on accident rates at roundabouts in Australia, Arndt (1991) confirmed that roundabout arms with a large entry path curvature and high approach speeds tend to have more single vehicle accidents and that risk for this accident group is increased if the central island is difficult for drivers to recognise from the approach arms.

Robinson (1998) reported on roundabouts in New South Wales in Australia and concluded that excessive approach speed is a major cause of single vehicle accidents.

A French study by Alphand et al (1991A) found that out of 33 single vehicle accidents on the circulatory carriageway, 17 involved mopeds and 5 motorcycles. These were thought to be due mainly to excessive speed for vehicles turning left (right in countries that drive on the left) and sometimes the presence of oil or gravel.

4.9.2 Approaching accidents (lane changing and rear shunts)

Maycock and Hall (1984) found that at 4-arm roundabouts in the UK, wider entries had a lower risk of approaching accidents.

In an Australian study of 100 roundabouts in Queensland, Arndt and Troutbeck (1995) concluded that, in order to minimize rear shunt accident rates, it is important to limit the 85th percentile speed on the approaches to roundabouts to around 60 km/h.

4.9.3 Entering-circulating accidents

At 4-arm roundabouts in the UK, Maycock and Hall (1984) found that the effect of entry path curvature on entering-circulating accidents was considerable. Roundabouts with no deflection had accident rates about 8.5 times those with maximum deflection, a result that led to modern roundabout design. The same study showed that wider entries are associated with higher risk of entering-circulating accidents. The authors concluded that roundabouts with heavily flared entries should have substantial entry path deflection.

In Australia, Arndt (1991) observed that roundabouts with a high speed approach have increased risk of entering-circulating accidents. Arndt and Troutbeck (1995) concluded that the speed of entering relative to circulating vehicles should be limited to around 35km/h, in order to reduce entering-circulating accident rates. They suggested using a small radius approach curve, narrowing the entry, exit and circulatory lanes, better positioning of the entry and exit arms and increasing the central island diameter as ways of reducing the relative speeds between entering and circulating vehicles.

4.9.4 Other vehicle accidents

Literature relating to ‘other vehicle’ accidents includes accidents to vehicles exiting the roundabout and accidents involving the rollover of heavy goods vehicles (HGVs).

Exiting accidents

Arndt (1991) noted that exits with small deflection islands and a small exit radius can result in accidents between entering and exiting vehicles. Anecdotal evidence in the UK suggests that large exit radii are desirable.

Rollover accidents

There are about 50 to 60 injury accidents per year in the UK involving rollover of HGVs. Load shedding is frequent at some grade-separated roundabouts where large changes in crossfall are combined with tight reverse horizontal curvature on moderately steep down gradients of about 5% (Brown, 1995). Even when there is no personal injury, this type of incident is expensive and can cause considerable delay.

When going ahead at a roundabout, a vehicle must follow a double bend rather than the continuous arc of a circle, which leads to load transfer and possible rollover for articulated vehicles. Unpublished research by TRL has shown that a double bend with a radius of curvature less than 50m, common at roundabouts, cannot be negotiated safely by articulated vehicles at speeds of more than 50km/hr. Articulated vehicles can overturn at speeds as low as 24km/hr on a curve of radius 20m (Kemp et al, 1978) and rollover is twice as likely as for rigid vehicles. Vehicles with high centres of gravity are most at risk. The TRL research did not allow for any effects of crossfall, but the simple analysis in Section 3.3.10 suggests that the effects are slightly worsened by outward crossfall but slightly improved by inward crossfall.

Arndt (1991) found in Australia that large diameter elliptical roundabouts in high speed environments with adverse crossfall on the circulatory lanes can lead to instability for heavy goods vehicles.

Alphand et al (1991A) reported that of 202 accidents at 179 urban roundabouts in France, 11 involved an HGV, of which one was a loss of control accident on the circulatory carriageway. Another paper by the same authors (Alphand et al, 1991B) suggests that roundabouts are not suitable where there are large numbers of HGVs, stating that rollover accidents are fairly frequent on some types of roundabout.

Unpublished research by TRL suggests that problem roundabouts have 5 main characteristics:

- Long straight high speed approach
- Little deflection before give way line
- Low circulating flow past entry
- Good visibility to the right
- Significant tightening of turn radius part way round the roundabout

The first four characteristics all make it easy for the driver to be deceived into approaching faster than is advisable and the fifth, a tightening of the turn part way round, is a trap for the unwary.

Conclusion: This advice should be propagated to designers and to freight operators.

4.9.5 Pedestrian accidents

UK studies (Maycock and Hall, 1984, Kennedy et al, 1998) show a relatively low proportion of accidents involving a pedestrian at both urban roundabouts (4% at small island and 8% at conventional roundabouts) and mini-roundabouts (15%). To some extent, the low proportion at UK roundabouts is due to:

- their location commonly being suburban rather than in the town centre
- pedestrians crossing beyond the flare may be outside the 20m limit of junction accidents

The latter does not apply to mini-roundabouts (which have at most a very short flare), however, suggesting that other explanations apply. Both types of junction benefit from a splitter island on the arm to assist pedestrians crossing the road. Drivers need to slow down as they approach the junction and may therefore be more alert than at other parts of the network. It is recognized, particularly in the US, that roundabouts may be harder to negotiate for people with a visual impairment than some types of junction.

Maycock and Hall did not find any design features that contributed to pedestrian accidents at roundabouts. They did not investigate the effect of pedestrian crossings.

4.9.6 Accidents involving two-wheelers

Accidents to pedal cyclists were not recorded separately by Maycock and Hall (1984), but a later study of these accidents at UK roundabouts (Layfield and Maycock, 1986) based on the same data showed that the risk for pedal cyclists and motorcyclists relative to cars is higher at roundabouts than at other junction types. Pedal cycles were involved in about 13 to 16% of accidents and motor cycles in 30 to 40%. About two-thirds of the 210 cycle accidents involved a cyclist on the circulatory carriageway and, in about half, a cyclist on the circulatory carriageway was hit by an entering vehicle. Later research (e.g. Davies et al, 1997) suggests that two-wheelers are most at risk when other traffic should give way to them.

Similarly Alphand et al (1991A) found that about half of entering-circulating accidents at 194 French roundabouts involved a two-wheeler, mostly at entries with more than one lane, and Harper and Dunn (2003) recorded for New Zealand roundabouts that two-wheelers were involved in 34% of all accidents and 64% of entering-circulating accidents. Robinson (1998) found similar figures in New South Wales (Australia) - 39% and 48% respectively.

Layfield and Maycock (1986) developed models for pedal cyclists and motor cyclists as separate groups. The results were similar to those for all vehicles, with entry path curvature and entry width again being the dominant terms. It was concluded that there was no particular aspect of geometric design that applies specifically to two-wheelers. However, as described in Section 3.4, later research has led to specific cyclist provision being introduced at some roundabouts. There is no equivalent for motorcyclists.

4.10 "Continental" roundabout design in the UK

4.10.1 Accident modelling of the effects of "continental" design

Using ARCADY, Davies et al (1997) modelled the effects of converting six UK roundabouts to a more "continental" design. The key features were:

- Radial rather than tangential entries
- Single lane entries and exits
- Minimal flare on the entries
- A central island diameter of 15-25m
- An inscribed circle diameter of 25-35m
- A circulatory carriageway width of 5-7m

Although the safety benefits for pedal cyclists may not be fully reflected in the ARCADY accident prediction model, the overall predicted safety effects were positive. The changes in geometry were considered to result in fewer entry-circulating accidents. The study concluded that 'there seems to be scope for improving the safety for cyclists of some roundabouts by applying a “continental” design to those with total inflows below about 2,500 vehicles/hour’.

4.10.2 UK experiments with “continental” design

Lawton et al (2003) describe four UK roundabouts which were converted to a more “continental” design, with tighter geometry, fewer entry and exit lanes. At one site, Toucan crossings (signal-controlled crossings for cyclists and pedestrians) were installed and cycle strips painted just ahead of the give way lines. There appeared to be an increase in perceived safety for cyclists, but there were not enough recorded accidents for any conclusions to be statistically reliable. The cycle strips appeared to deter motor vehicles from overshooting onto the roundabout. The more radial entries were considered to make it more likely that cyclists will be in the field of vision of drivers. The fact that entries and circulatory carriageway were both single lane was also considered likely to improve safety for cyclists.

5 Roundabout software

5.1 Specific roundabout models

There are various models specifically for roundabouts, as shown in Table 19.

Table 19: Roundabout models

		Capacity	**Delay**	**Queues**	**Accidents**	**Methodology**
ARCADY	UK	✓	✓	✓	✓	Empirical
RODEL	UK	✓	✓	✓	✓	Empirical
GIRABASE	France	✓	✓	✓	✓	Empirical
KREISEL	Germany	✓	✓	✓		Averages different procedures
SIDRA	Australia	✓	✓			Gap-acceptance
HCS-3	US	✓	✓			Gap-acceptance
ARNDT	Australia				✓	Empirical

The UK and German software handle flared entries. RODEL is intended to be engineering-friendly. It is, however, a DOS-based system, and does not include mini-roundabouts. Delay and queues at signalised roundabouts in the UK are modelled using TRANSYT, but this software does not model accidents.

5.2 Microscopic simulation of roundabouts

The main microscopic simulation models are as follows:

- Paramics - UK
- VISSIM – Germany
- AIMSUM - Spain
- CORSIM - US
- Integration - US
- Simtraffic - US

Microscopic simulation models are finding increasing acceptance as a means of demonstrating the performance and behaviour of road networks. The main reason for this is the visualisation of the network and vehicles running on it. Another advantage is the ability to include different types of junction within one model. Thus it is possible to model a complete town centre and surrounding hinterland, include all junctions, whether they are signal controlled, priority or roundabouts. Dynamic route assignment can also be included so that the effect of policy decisions can be assessed. Models such as CONTRAM and SATURN can do the same job, but without the visualisation aspect.

Microscopic simulation models could be used as a means of modelling individual roundabouts and there are obvious attractions in doing so. However, there are some pitfalls which may not necessarily be obvious, especially if the resulting visualisation looks to be an accurate representation of real-life. Table 20 considers the issues when comparing micro-simulation models with the empirical model as used by ARCADY.

The underlying means of defining capacity within microscopic simulation models is the use of 'gap-acceptance'. So at a give way entry to a roundabout, a vehicle waiting to enter the circulating section will do so once there is a gap of a pre-defined or pre-specified temporal size. Normally, the gap is not specified directly; rather it is deduced from other parameters that define vehicle behaviour. Such parameters vary considerably as to how precise they might be and as to how easy they are to validate or measure, and there are a number of them. For example, 'aggressiveness' is one variable that can be adjusted, but is impossible to measure. Nevertheless, by adjusting a few key parameters, micro-simulation models can be calibrated to reflect the capacity of a particular situation with acceptable accuracy. This is a necessarily manual iterative procedure and requires the collection of a significant amount of data with which to establish the on-street capacity that is being duplicated in the model.

Micro-simulation models have two further fundamental aspects to their method of modelling: Firstly, vehicles are modelled on tracks; and secondly, a car-following model is employed. The use of tracks limits the scope of geometry that can be taken into account. For example it is not possible to take direct account for the behaviour of vehicles when a lane is widened. The car following model attempts to translate driver behavioural parameters into a distance between following vehicles. Car-following models are very sophisticated and there has been plenty of research into driver behaviour that is helping to produce better ones. However, it is fair to say that even the most sophisticated of human models are likely to be a vast simplification of real life, and will remain so for a significant period yet.

In contrast to micro-simulation models, users of ARCADY have to feed known geometric parameters into the model, from which capacity is estimated. The geometric parameters are straightforward to measure and are exact (even if measuring them may not be).

All of which leads to the principal drawback with micro-simulation models: that is the difficulty of estimating the capacity of a roundabout under a change of circumstances – and a change means any change, including flows. The reason for this is that in validating a model to replicate a known capacity by adjusting a set of un-measurable parameters, those parameters are highly unlikely to be suitable when there is a change in circumstances to consider.

To illustrate just one situation that is relevant to roundabouts, consider an entry that has a single, fairly narrow lane catering for all movements (i.e. left, straight and right) feeding a roundabout with two circulating lanes. These vehicles will have to queue one behind another leaving the normal 1 to 2 metres between them. Suppose this entry is now widened, or flared; not enough to make two separate lanes, but to, say, 1½ lanes. Vehicles will still not be able to queue side-by-side, but will be able to anticipate the lane they are about enter so that queuing becomes 'staggered'. This means that the staggered vehicles are likely to follow each other more closely, making entry to the roundabout more efficient. Capacity will increase in this scenario (and the data behind the empirical relationships prove this to be so). The use of ARCADY will give a different estimate for the two lane-widths and should at least accurately reflect the difference between the two (and hopefully the absolute value of capacity as well). Micro-simulations would not lend themselves to the analysis of such a change – they could be altered to reflect the increase in capacity, but they could not be altered so that the increase in capacity can be calculated.

Calibration and validation of a microscopic simulation model of a roundabout is not necessarily an easy task. Furthermore, providing and reviewing evidence about the standard of calibration of a particular model can be a substantial task in itself. Most in the industry appreciate this and it seems likely that the required effort is applied. However, the actual standard of accuracy achieved is unclear.

When calibrating an ARCADY model, it is advisable to measure the capacity of each entry directly by coincidental measurement of the circulating and entry flows under congested conditions. This allows a site-specific correction factor to be calculated. It is thought, however, that even this is not often carried out. Instead, judging from the enquiries TRL receives on the technical application of ARCADY, many choose to calibrate their models against queue lengths, often from a single day's data. This is not acceptable because queue lengths can be highly variable even under very similar circumstances.

In conclusion, the main choice as to how to model priority control roundabouts for users in the UK is between ARCADY (or RODEL, which uses the same capacity relationships as ARCADY) and the various microscopic simulation models. The authors have strived to remain impartial in writing this, even though TRL are the vendors of ARCADY and were responsible for the research that led to the empirical relationships used within it. However, the way in which the two types of model operate is fundamentally different. ARCADY's empirical approach firstly established the geometric link with capacity, and secondly allows the capacity to be estimated from known geometric parameters. Thus the method has been established and accepted as accurate over nearly 20 years. In fact, in the United States, RODEL is becoming the application of choice in a number of states despite being an outdated DOS program and having widely promoted competition from SIDRA (which uses gap-acceptance modelling techniques). Microscopic simulations, on the other hand, whilst ideally suited to some traffic modelling tasks, and to the visualisation of the road network, still have limitations when it comes to modelling priority roundabouts, especially when there is a need to consider alternative or yet-to-exist scenarios.

Table 20: Comparison of microscopic simulation models with ARCADY

	Ability		Validation effort		
Modelling requirement	ARCADY	Micro-sim	ARCADY	Micro-sim	Comments
Entry capacity of existing situations	Good	Good	Medium	High	Micro-sim models can be calibrated/validated to match the capacity of the real situation, although this is far from trivial. ARCADY should also be calibrated in such situations, but needs less data to do so, although this is not always done in the most appropriate way.
Entry capacity of proposed situations	Good	Poor	Low	High	Micro-sim models are not suitable for modelling proposed situations. See text. ARCADY can be used because the capacity can be estimated from known/measurable geometric parameters.
Exit blocking	NA	Adequate	NA	Medium	
Maximum queue length of existing situations	Good	Good	Low	Low	Estimates of queue length are made from the capacity and flows. Thus calibration/validation effort should go towards measuring capacity. Queue lengths should not be used to calibrate/validate
Maximum queue length of proposed situations	Good	Poor	Low	Low	Micro-sim models are poor for the same reasons as 'Entry capacity of proposed situations'
Queue-length variation of existing situations	Good	Good	Low	Low	As for maximum queue
Queue-length variation of proposed situations	Good	Poor	Low	Low	As for maximum queue
Delay estimation for existing situations	Good	Good	Low	Low	Based on flow, queues and capacity. See above
Delay estimation for proposed situations	Good	Poor	Low	Low	Based on flow, queues and capacity. See above
Zebra crossings	Good	Good	Low	Medium	
Pelican crossings	Good	Good	Medium	Medium	
Entry speed	NA	Adequate	NA	Medium	Estimating speeds may be useful for confirming entry path deflection etc. But there would have to be some validation of the behavioural parameters.
Exit speed	NA	Adequate	NA	Medium	As above
Circulating speed	NA	Adequate	NA	Medium	As above
Pedestrian movements	NA	Adequate	NA	Low	Pedestrian movements can be modelled in micro-sims, but some models are better suited to this than others.

	Ability		Validation effort		
Modelling requirement	ARCADY	Micro-sim	ARCADY	Micro-sim	Comments
Accident prediction	Good	NA	Medium	NA	ARCADY contains a separate model for accidents (also available in SafeNET) with some cross-over of the data used in the capacity model. The accident prediction relationships could be included in any package, or be stand-alone. Micro-sims cannot model collision risk through the limited (compared with real life) behavioural parameters used (even though some users have thought this might be possible!)
Pollution modelling	NA	Adequate	NA	Low	Some micro-sims include pollution modelling. ARCADY as yet does not.

6 Summary and recommendations

6.1 Summary

Compared with the UK standard, the roundabout designs in the guidelines in Germany, France and the Netherlands are notably smaller and have a tighter geometry which leads to lower circulating speeds.

This generally smaller design is reflected in the fact that in those countries, roundabouts are mainly used for reasons of road safety. Other differences that also reflect this different approach are that design features that are used to increase capacity on UK roundabouts (flared entries, segregated left turns and tangential entries) are not recommended in Germany, France and the Netherlands, because they tend to lead to higher circulating speeds.

Single lane roundabouts are generally preferred over double lane roundabouts on safety grounds (the French guidelines do not even provide recommendations for urban double lane roundabouts and the German guidelines on urban double lane roundabouts are considerably less detailed and prescriptive than the single lane ones).

Australian guidelines appear to be more comparable with the UK standard, probably because of the greater emphasis given to capacity than in continental Europe.

The American guidelines provide a range of different types of roundabouts, in which the higher-capacity types (for use on arterials) are more comparable with the UK and Australian design standards and the compact type (for use on local urban roads) shows more similarity to the German, French and Dutch designs.

The amount of information traced on Swedish, Danish and Norwegian guidelines was relatively limited, but showed designs that are generally larger than those in Germany, France and the Netherlands.

Detailed information on the design of cyclist provision is given in German, French and Dutch guidelines. A more limited description of cycle provision is given in the Danish, Australian, UK and American guidelines.

A notable difference is that none of the overseas guidelines studied recommend inward crossfall on roundabouts. Except for mini-roundabouts, inward crossfall is recommended for UK roundabouts on all or part of the circulatory carriageway.

6.2 Conclusions

The conclusions were as follows:

- The inscribed circle diameter should not be unnecessarily large. In particular, if the roundabout is at-grade, the inscribed circle at diameter should not exceed 100m.
- A truck apron (overrun area i.e. raised low-profile areas around a central island) should continue to be used at small roundabouts if there is sufficient land-take to use a solid island roundabout rather than a mini-roundabout. The edge profile of a truck apron in TD 16/93 is allowed to be up to 50mm. In order to be consistent with the Traffic Calming Regulations, the vertical face should not exceed 15mm. The apron should be capable of being mounted by the trailer of a large goods vehicle, but be unattractive to cars e.g. by having a slope and/or textured surface.
- Outward crossfall should be permitted on smaller roundabouts in urban areas.
- Lane widths at entry should remain at 3m to 3.5m at multilane entries, but at single lane entries, the width should be 4.5m.

- Adding an extra lane at roundabout entries should require justification rather than being automatic. The recommended effective flare lengths of 5m (urban) and 25m (rural) should remain.
- Suitable values for the entry (kerb) radius are 20m at larger roundabouts, 10-15m at smaller roundabouts.
- Suitable values for the exit (kerb) radius are 20-100m at larger roundabouts, 15-20m at smaller roundabouts.
- Suitable values for the entry angle are 20 to 60 degrees, particularly at smaller roundabouts.
- Flaring should continue to be used in preference to a segregated left turn lane as this requires less land take and is safer for non-motorised road users.
- The entry path radius on any approach should not exceed 100m. It should not exceed 70m at small urban roundabouts.

Cycle lanes should not be used on the circulatory carriageway. Cyclists should mix with traffic at urban roundabouts with low flow. External cycle paths are the best facility at larger urban roundabouts.

Where vehicle flow is low, an informal crossing (a dropped kerb) is generally adequate for pedestrians. At medium flows, where there is a substantial pedestrian demand, a formal crossing should be provided close to the roundabout (but upstream of any flaring). Where a signal controlled pedestrian or cycle crossing is provided, it should be either at 20m or at least 50m from the give way line to avoid confusion with the roundabout itself and to minimize queueing back onto the circulatory carriageway.

On dual carriageway roads, or single carriageway roads with a long splitter island, visibility to the right may be limited by use of planting or other screening (at least 2m high) until vehicles are within 15m of the give way line, to reduce excessive entry speeds.

The possibility of rollover of large vehicles should be minimized by keeping approach speeds low and ensuring that roundabouts have no abrupt changes in geometry.

6.3 Recommendations

There is scope for introducing in the UK Standard a new “compact” roundabout with single lane entries, exits and circulatory carriageway, with minimal flaring (see Figure 41). This style of roundabout would be most appropriate on low flow, local roads, where there were substantial numbers of pedestrians and cyclists. In urban areas, the design would incorporate tighter geometry and outward crossfall, in order to slow traffic; it would be suitable for regular pedestrian and cyclist use. This compact roundabout would form part of a design hierarchy (see Section 7) to depend on road type, whether the speed limits on the approach roads exceed 40mph and on the levels of vehicle and non-motorised user flow. If required, pedestrian provision would comprise Zebra crossings at 5m from the give way line. No special provision for cyclists would be necessary.

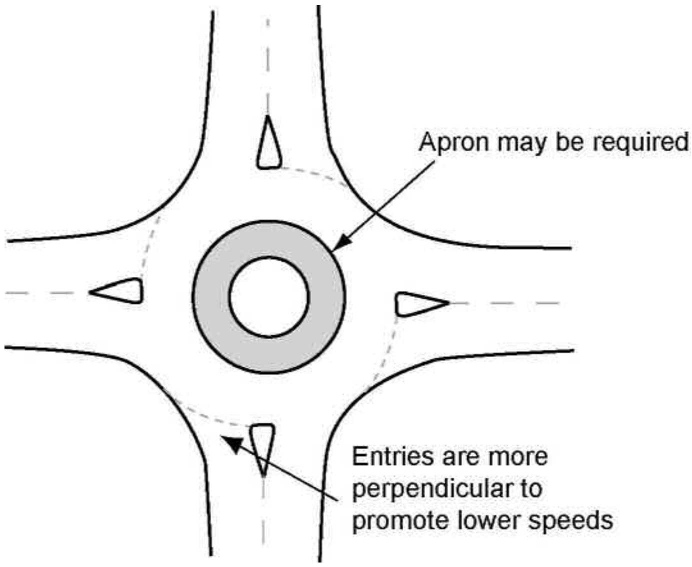


Figure 41: Possible layout for compact roundabout

7 Design hierarchy

The types of roundabout are Signalised, Grade Separated, Dual Carriageway (one or more approaches is dual carriageway), Normal (all approaches are single carriageway and design broadly follows TD 16/93), Compact ("continental style", with single lane entry, exit and circulatory carriageway) and Mini-roundabout.

The various factors for the design hierarchy are as follows:

- Speed limit within 100m of give way line (>40mph, ≤40mph)
- Single or dual-carriageway
- Level of vehicle flow
- Level of cyclist flow
- Level of pedestrian flow

At a roundabout with one or more dual carriageway arms, or a busy single carriageway roundabout, the design should be similar to that in TD 16/93. If there is a non-motorised user need, it should be catered for by use of a signal controlled crossing (Puffin, Toucan or Equestrian as appropriate). In circumstances where there is a need for a signal controlled crossing on more than one arm, a signalised roundabout may be preferable.

At a single carriageway roundabout with medium flow, the design will again be similar to that in TD 16/93. If warranted, either a signal controlled or a Zebra crossing should be used, depending on the speed limit and the level of flow.

Where total inflow is below 8,000 vehicles per day, cycle facilities are not necessary, but on some occasions, a pedestrian crossing (a Zebra or possibly a signal controlled crossing) should be provided.

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Appendix A. International design guidelines (Spring 2004)

A.1 France

Guidelines for mini- and urban roundabouts are given in CERTU (1997 and 1999) respectively, summarised by Guichet (1997). Mini-roundabouts are recommended only for minor roads. Urban double lane roundabouts are not recommended for safety reasons. SETRA (1998) gives guidelines for roundabouts in rural areas.

There are no recommendations for provision for cyclists or pedestrians at rural roundabouts. In urban areas, the following types of cycle provision are mentioned in the guidelines:

Mixed use

- Recommended if outside diameter is smaller than 44m. The speed of cars should be comparable to that of cyclists
- If a cycle lane is present on the approach, it should be ended 15m before the give way line

Cycle lane

- Recommended if outside diameter is larger than 44m. Width of cycle lane 1.5 – 2.0m, separated from carriageway with a dotted line.

Cycle path

- Crossings combined with pedestrian crossings. Cyclists must give way to other vehicles on the approaches

Urban mini-roundabouts in France

The French guidelines recommend mini-roundabouts only for secondary roads in urban areas and only with 3 or 4 arms.

Design elements	**Dimensions**
	Mini roundabout
GENERAL	
Maximum entering lanes per approach	1
Recommended maximum entry design speed	Maximum speed limit 50 or 30 km/h
Recommended design speed on roundabout	
Entries radial or tangential	Radial
Overturning of large goods vehicles	
Design vehicle	
CENTRAL PART	
Inscribed circle diameter	15 - 24 m
Circulatory carriageway width	6 - 9.50 m
Crossfall	Outward 1.5 – 2.5 %
CENTRAL ISLAND	
Truck apron present	No
Material truck apron	-
Central island diameter (including truck apron)	3 – 5 m
Truck apron width	-
Height of central island	0.10 – 0.15 m
Landscaping	-
Visibility requirements	
Island needs to be perfect circle	
APPROACHES/EXITS	
Entry width (no. of lanes)	2.50 – 3.50 m
Exit width (no. of lanes)	2.75 – 3.50 m
Entry radius	
Exit radius	
Speed reduction on approach	
Entry flare permitted?	Not relevant
Length of entry flare	Not relevant
Right turn bypass permitted?	Not relevant
CROSSING FACILITIES PEDESTRIANS/CYCLISTS	
Distance between crossing and outside circ. carriageway	
DEFLECTION ISLAND	
Deflection island present	Yes
Length of deflection island	
Width of deflection island	0.85 – 2.00 m
ROAD MARKINGS	
Markings on roundabout	
Marking on approach	
Markings on yield line	Yield markings (continuous or dotted line)
LIGHTING	
Lighting recommendations on roundabout	
Lighting recommendations on approaches	

Urban single lane roundabouts in France

Design elements	Dimensions
GENERAL	
Maximum entering lanes per approach	1
Recommended maximum entry design speed	Maximum speed limit 50 km/h
Recommended design speed on roundabout	
Entries radial or tangential	Radial
Overturning of large goods vehicles	
Design vehicle	
CENTRAL PART	
Inscribed circle diameter	> 30 m
Circulatory carriageway width	7 - 8 m
Crossfall	Outward 1.5 – 2.5%
CENTRAL ISLAND	
Truck apron present	Yes
Material truck apron	Rough material
Central island diameter (including truck apron)	> 12m island + 4m truck apron (total > 16m)
Truck apron width	1.5 – 2.0 m (4% crossfall)
Height of central island	
Landscaping	
Visibility requirements	Entering drivers should only be able to see first (left) quarter of roundabout from 15m before entry-point.
Island needs to be perfect circle	Yes
APPROACHES/EXITS	
Entry width (no. of lanes)	3.5 – 4.0 m (3.0m allowed for very narrow streets)
Exit width (no. of lanes)	4.0 –4.5 m
Entry radius	10 – 15 m
Exit radius	15 – 20 m
Speed reduction on approach	No
Entry flare permitted?	Not relevant
Length of entry flare	Not relevant
Right turn bypass permitted?	No
CROSSING FACILITIES PEDESTRIANS/CYCLISTS	
Distance between crossing and outside circ. carriageway	2 – 5 m
DEFLECTION ISLAND	
Deflection island present	Yes
Length of deflection island	
Width of deflection island	0.8 – 2 m
ROAD MARKINGS	
Markings on roundabout	No
Marking on approach	
Markings on yield line	Block markings
LIGHTING	
Lighting recommendations on roundabout	Yes; lighting poles around circ. carriageway
Lighting recommendations on approaches	

Rural single lane roundabouts in France

Design elements	**Dimensions**
GENERAL	
Maximum entering lanes per approach	1
Recommended maximum entry design speed	Maximum speed limit 50 km/h
Recommended design speed on roundabout	< 50 km/h
Entries radial or tangential	Radial
Overturning of large goods vehicles	
Design vehicle	
CENTRAL PART	
Inscribed circle diameter	> 30 m (on secondary network, 24 – 30 m is acceptable)
Circulatory carriageway width	7 - 8 m
Crossfall	Outward 1.5 – 2.0 %
CENTRAL ISLAND	
Truck apron present	Yes
Material truck apron	Rough material
Central island diameter (including truck apron)	> 12 m island + 4 m truck apron (tot. >16 m)
Truck apron width	3.50 m (4% crossfall) 1.5 – 2.0 m for small inscribed circle diameters)
Height of central island	"Island needs to have volume"; No hard obstacles. Obstacles at least 2 m from edge of island.
Landscaping	
Visibility requirements	Entering drivers should only be able to see first (left) quarter of roundabout from 15 m before entry-point.
Island needs to be perfect circle	Yes
APPROACHES/EXITS	
Entry width (no. of lanes)	4.0 m
Exit width (no. of lanes)	4.0 –5.0 m
Entry radius	10 – 15 m
Exit radius	15 – 30 m
Speed reduction on approach	No
Entry flare permitted?	Not relevant
Length of entry flare	Not relevant
Right turn bypass permitted?	Preferably not
CROSSING FACILITIES PEDESTRIANS/CYCLISTS	
Distance between crossing and outside circ. carriageway	
DEFLECTION ISLAND	
Deflection island present	Yes
Length of deflection island	
Width of deflection island	
ROAD MARKINGS	
Markings on roundabout	No
Marking on approach	
Markings on yield line	Block markings
LIGHTING	
Lighting recommendations on roundabout	Not necessary (only if immediate proximity is lit).
Lighting recommendations on approaches	

Rural double lane roundabouts in France

Design elements	**Dimensions**
GENERAL	
Maximum entering lanes per approach	2
Recommended maximum entry design speed	
Recommended design speed on roundabout	< 50 km/h
Entries radial or tangential	Radial
Overturning of large goods vehicles	
Design vehicle	
CENTRAL PART	
Inscribed circle diameter	50 m
Circulatory carriageway width	8.5 – 10.0 m
Crossfall	Outward 1.5 – 2.0 %
CENTRAL ISLAND	
Truck apron present	No
Material truck apron	
Central island diameter (including truck apron)	> 30.0 m
Truck apron width	
Height of central island	"Island needs to have volume"; No hard obstacles. Obstacles at least 2 m from edge of island.
Landscaping	
Visibility requirements	Entering drivers should only be able to see first (left) quarter of roundabout from 15 m before entry-point.
Island needs to be perfect circle	Yes
APPROACHES/EXITS	
Entry width (no. of lanes)	6 – 7 m (2)
Exit width (no. of lanes)	7 m (2)
Entry radius	10 – 15 m
Exit radius	15 – 20 m
Speed reduction on approach	No
Entry flare permitted?	No
Length of entry flare	
Right turn bypass permitted?	Preferably not
CROSSING FACILITIES PEDESTRIANS/CYCLISTS	
Distance between crossing and outside circ. carriageway	
DEFLECTION ISLAND	
Deflection island present	Yes
Length of deflection island	
Width of deflection island	
ROAD MARKINGS	
Markings on roundabout	No
Marking on approach	
Markings on yield line	Block markings
LIGHTING	
Lighting recommendations on roundabout	Not necessary (only if immediate proximity is lit.
Lighting recommendations on approaches	

A.2 Germany

The German guidelines (Schnüll and Goltermann, 2000, Forschungsgesellschaft für Strassen- und Verkherswesen, 1993, 1998 and 2004) provide separate recommendations for urban and rural designs for single lane roundabouts, but not for double lane roundabouts. In general, the guidelines for double lane roundabouts (Forschungsgesellschaft für Strassen- und Verkherswesen, 1993) are far less extensive than those for single lane roundabouts. Although the guidelines focus mainly on urban design, they also apply to rural situations.

The most recent guidelines (Forschungsgesellschaft für Strassen- und Verkherswesen, 2004) include the design of mini-roundabouts. In addition, they describe 3 methods of increasing capacity at single lane roundabouts:

1. Segregated right turn lane
2. Wide (2 lanes, but no markings) circulatory carriageway
3. Two-lane entries where necessary

These are intended to be applied in order.

The following facilities for pedal cycles on roundabouts are described in Haller et al (2000):

Mix with traffic

- Traffic volume on roundabout lower than 15,000 motor vehicles/day
- Circulatory carriageway must be narrow, to ensure cars do not overtake pedal cyclists on the roundabout (pedal cycles in between other vehicles; not parallel)
- Additional importance of speed reducing design

Cycle lane on roundabout:

- Not recommended because of its poor safety record.

Cycle path without priority for pedal cycles:

- Only recommended in rural areas; in urban areas, priority should preferably be given to cyclists
- Crossing at 4m from outside edge of circulatory carriageway
- Deflection island on arms length 2.50m
- “Streaming” area for cyclists (where cycle lane joins cycle path) before crossing >2m long
- Approach to crossing (for pedal cycles) at a sharp angle, to emphasise priority situation

Cycle path with priority for pedal cycles:

- Recommended in urban areas
- Crossing at 2 – 4m from outside edge of circulatory carriageway
- Cycle path around roundabout follows shape of roundabout (ring-shaped) to emphasise priority situation.

Both options with cycle paths can be used for single lane and double lane roundabouts.

Note that in the German guidelines, the circulatory carriageway width includes the width of the truck apron. The values in the tables have been adjusted for ease of comparison with other countries.

Urban mini-roundabouts in Germany

Design elements	Dimensions
GENERAL	
Maximum entering lanes per approach	1
Recommended maximum entry design speed	
Recommended design speed on roundabout	
Entries radial or tangential	Radial
Overturning of large goods vehicles	
Design vehicle	
CENTRAL PART	
Inscribed circle diameter	13 – 24 m
Circulatory carriageway width	5.0 – 4.5 m
Crossfall	Outward 2.5%
CENTRAL ISLAND	
Truck apron present	
Material truck apron	
Central island diameter (including truck apron)	
Truck apron width	
Height of central island	12cm
Landscaping	No
Visibility requirements	.
Island needs to be perfect circle?	Yes
APPROACHES/EXITS	
Entry width (no. of lanes)	3.25 – 3.50 m (1)
Exit width (no. of lanes)	3.50 – 3.75 m (1)
Entry radius	10 – 12 m
Exit radius	12 – 14 m
Speed reduction on approach	
Entry flare permitted?	
Length of entry flare	
Right turn bypass permitted?	
CROSSING FACILITIES PEDESTRIANS/CYCLISTS	
Distance between crossing and outside circ. carriageway	
DEFLECTION ISLAND	
Deflection island present	Yes
Length of deflection island	
Width of deflection island	
ROAD MARKINGS	
Markings on roundabout	
Marking on approach	No
Markings on yield line	Broken line on entry and exit
LIGHTING	
Lighting recommendations on roundabout	When approaches are lit, lighting columns around roundabout. Position on deflection islands, between arms, or at crossing facilities
Lighting recommendations on approaches	

Cyclists mix with traffic at mini-roundabouts.

Urban single lane roundabouts in Germany

Design elements	Dimensions
GENERAL	
Maximum entering lanes per approach	1
Recommended maximum entry design speed	
Recommended design speed on roundabout	20 – 40 km/h
Entries radial or tangential	Radial
Overturning of large goods vehicles	
Design vehicle	Largest expected vehicle
CENTRAL PART	
Inscribed circle diameter	26 – 45 m
Circulatory carriageway width	6.5 – 10 m
Crossfall	Outward 2.5%
CENTRAL ISLAND	
Truck apron present	Yes
Material truck apron	Textured surface
Central island diameter (including truck apron)	14.6 – 25.7 m
Truck apron width	2.30 – 1.85 m
Height of central island	
Landscaping	
Visibility requirements	On approach forward vision should be obstructed.
Island needs to be perfect circle?	Yes
APPROACHES/EXITS	
Entry width (no. of lanes)	3.25 – 3.50 m (1)
Exit width (no. of lanes)	3.50 – 3.75 m (1)
Entry radius	10 – 12 m
Exit radius	12 – 14 m
Speed reduction on approach	
Entry flare permitted?	
Length of entry flare	
Right turn bypass permitted?	Permitted
CROSSING FACILITIES PEDESTRIANS/CYCLISTS	
Distance between crossing and outside circ. carriageway	
DEFLECTION ISLAND	
Deflection island present	Yes
Length of deflection island	
Width of deflection island	
ROAD MARKINGS	
Markings on roundabout	
Marking on approach	No
Markings on yield line	Broken line on entry and exit
LIGHTING	
Lighting recommendations on roundabout	When approaches are lit, lighting columns around roundabout. Position on deflection islands, between arms, or at crossing facilities
Lighting recommendations on approaches	

If traffic volumes are less than 15,000 vehicles per day, cyclists mix with traffic on the roundabout.
If traffic volumes are higher than this, cycle facilities should be separate cycle paths at 4-5m from the give way line.

Urban double lane roundabouts in Germany

Design elements	Dimensions
GENERAL	
Maximum entering lanes per approach	2
Recommended maximum entry design speed	Not specified
Recommended design speed on roundabout	Not specified
Entries radial or tangential	Radial
Overturning of large goods vehicles	
Design vehicle	
CENTRAL PART	
Inscribed circle diameter	> 40 m
Circulatory carriageway width	Not specified
Crossfall	Outward 2.5%
CENTRAL ISLAND	
Truck apron present	No
Material truck apron	
Central island diameter (including truck apron)	> 10 m
Truck apron width	
Height of central island	Not specified
Landscaping	Optional
Visibility requirements	Not specified
Island needs to be perfect circle?	Not necessarily
APPROACHES/EXITS	
Entry width (no. of lanes)	Not specified
Exit width (no. of lanes)	Not specified
Entry radius	Not specified
Exit radius	Not specified
Speed reduction on approach	
Entry flare permitted?	Yes
Length of entry flare	Not specified
Right turn bypass permitted?	Not specified
CROSSING FACILITIES PEDESTRIANS/CYCLISTS	
Distance between crossing and circulatory cway	4 – 5 m
DEFLECTION ISLAND	
Deflection island present	Yes
Length of deflection island	
Width of deflection island	
ROAD MARKINGS	
Markings on roundabout	Yes; lane separation markings
Marking on approach	Lane markings
Markings on yield line	Priority markings on entry; no markings on exit
LIGHTING	
Lighting recommendations on roundabout	Not specified
Lighting recommendations on approaches	Not specified

Cycle facilities should be separate cycle paths.

Rural single lane roundabouts in Germany

Design elements	**Dimensions**
GENERAL	
Maximum entering lanes per approach	1
Recommended maximum entry design speed	
Recommended design speed on roundabout	20 – 40 km/h
Entries radial or tangential	Radial
Overturning of large goods vehicles	
Design vehicle	Largest expected vehicle
CENTRAL PART	
Inscribed circle diameter	35 – 45 m
Circulatory carriageway width	6.50 – 5.75 m
Crossfall	Outward 2.5%
CENTRAL ISLAND	
Truck apron present	No
Material truck apron	
Central island diameter (including truck apron)	22 – 33.50 m
Truck apron width	
Height of central island	
Landscaping	
Visibility requirements	On approach forward vision should be obstructed.
Island needs to be perfect circle?	
APPROACHES/EXITS	
Entry width (no. of lanes)	3.50 – 4.00 m (1)
Exit width (no. of lanes)	3.50 – 4.25 m (1)
Entry radius	12 – 14 m
Exit radius	14 – 16 m
Speed reduction on approach	
Entry flare permitted?	
Length of entry flare	
Right turn bypass permitted?	Permitted
CROSSING FACILITIES PEDESTRIANS/CYCLISTS	
Distance between crossing and outside circ. carriageway	
DEFLECTION ISLAND	
Deflection island present	
Length of deflection island	
Width of deflection island	
ROAD MARKINGS	
Markings on roundabout	No
Marking on approach	
Markings on yield line	Broken line on entry and exit
LIGHTING	
Lighting recommendations on roundabout	Not necessary
Lighting recommendations on approaches	Not necessary

Cycle facilities should be separate cycle paths.

Rural double lane roundabouts in Germany

Guidelines for double lane roundabouts are far less extensive than the guidelines for guidelines for single lane roundabouts.

No separate guidelines are given for urban and rural double lane roundabouts. Although the guidelines mainly focus on urban design, the guidelines can be applied to rural situations.

Design elements	**Dimensions**
GENERAL	
Maximum entering lanes per approach	2
Recommended maximum entry design speed	Not specified
Recommended design speed on roundabout	Not specified
Entries radial or tangential	Radial
Overturning of large goods vehicles	
Design vehicle	
CENTRAL PART	
Inscribed circle diameter	> 40 m
Circulatory carriageway width	Not specified
Crossfall	Outward 2.5%
CENTRAL ISLAND	
Truck apron present	No
Material truck apron	
Central island diameter (including truck apron)	> 10 m
Truck apron width	
Height of central island	Not specified
Landscaping	Optional
Visibility requirements	Not specified
Island needs to be perfect circle?	Not necessarily
APPROACHES/EXITS	
Entry width (no. of lanes)	Not specified
Exit width (no. of lanes)	Not specified
Entry radius	Not specified
Exit radius	Not specified
Speed reduction on approach	
Entry flare permitted?	Yes
Length of entry flare	Not specified
Right turn bypass permitted?	Not specified
CROSSING FACILITIES PEDESTRIANS/CYCLISTS	
Distance between crossing and outside circ. carriageway	5 – 6 m
DEFLECTION ISLAND	
Deflection island present	Yes
Length of deflection island	
Width of deflection island	
ROAD MARKINGS	
Markings on roundabout	Yes; lane separation markings
Marking on approach	Lane markings
Markings on yield line	Priority markings on entry; no markings on exit
LIGHTING	
Lighting recommendations on roundabout	Not specified
Lighting recommendations on approaches	Not specified

Cycle facilities should be separate cycle paths.

A.3 The Netherlands

The use of roundabouts in the Netherlands has become increasingly popular since the 1980s, mainly due to their good safety record. The fact that roundabouts in the Netherlands are generally regarded as a road safety measure has had an important effect on the design characteristics and guidelines. The roundabouts are generally small, with tight geometry to reduce speeds.

The Dutch guidelines (CROW, 1998) describe single and double lane roundabouts for both rural and urban situations. The larger diameters of roundabouts in rural areas are caused not so much by higher design speeds (both rural and urban roundabouts have comparably low design speeds), but by their more frequent use by large vehicles.

Although double lane roundabouts are described, the guidelines recommend the use of single lane roundabouts, because of their better safety performance. Generally, double lane roundabouts are only used when absolutely necessary for capacity reasons.

CROW (1996) gives guidelines for the design of mini-roundabouts.

Special attention is given in the guidelines to provision for cyclists. All the roundabout types described in the guidelines have some form of cyclist provision. The following types of pedal cycle facilities are described:

Mix with traffic

- Recommended in situations with low traffic volumes (total inflow < 6,000 vehicles per day)
- Width of the circulatory carriageway should be limited

    To prevent cyclists being in the blind spot of drivers exiting the roundabout

    To force cars and cyclists to drive behind each other (instead of next to each other)

Cycle lanes (paths)

- In urban areas, priority for cyclist on (around) the roundabout over vehicles on the approaches is recommended
- In rural areas, the design without priority for cyclists on the roundabout is recommended

Although roundabouts with cycle lanes on the circulatory carriageway have been used in urban areas in the Netherlands, they are not recommended in the guidelines (CROW, 2002). Where traffic volumes are low, cycle lanes are not needed since mixed traffic is considered to be a better solution; with higher volumes, the recommended solution is a separate cycle path. Cycle lanes on the circulatory carriageway have proved to be less safe for cyclists, because:

- cyclists are in the blind spot of car drivers leaving the roundabout
- adding a cycle lane widens the circulatory carriageway, enabling higher speeds.

If this type of roundabout is used, the guidelines recommend providing a narrow (1m) separation (kerb) between the cycle lane and the rest of the traffic.

The guidelines recommend the use of separate cycle paths without priority for cyclists on the crossings on connecting roads (i.e. cyclists have to give priority to vehicles on approaches).

Urban mini-roundabouts in the Netherlands

Design elements	**Dimensions**
	Mini roundabout
GENERAL	
Maximum entering lanes per approach	1
Recommended maximum entry design speed	< 50 km/h
Recommended design speed on roundabout	-
Entries radial or tangential	Radial
Overturning of large goods vehicles	-
Design vehicle	
CENTRAL PART	
Inscribed circle diameter	10 to 20 m
Circulatory carriageway width	
Crossfall	
CENTRAL ISLAND	
Truck apron present	Not relevant
Material truck apron	Not relevant
Central island diameter (including truck apron)	≥ Carriageway width
Truck apron width	Not relevant
Height of central island	0.10 to 0.14 m no obstacles. Central island mountable.
Landscaping	-
Visibility requirements	-
Island needs to be perfect circle	Yes
APPROACHES/EXITS	
Entry width (no. of lanes)	-
Exit width (no. of lanes)	-
Entry radius	-
Exit radius	-
Speed reduction on approach	-
Entry flare permitted?	No
Length of entry flare	
Right turn bypass permitted?	No
CROSSING FACILITIES PEDESTRIANS/CYCLISTS	
Distance between crossing and outside circ. carriageway	
DEFLECTION ISLAND	
Deflection island present	No
Length of deflection island	-
Width of deflection island	
ROAD MARKINGS	
Markings on roundabout	
Marking on approach	-
Markings on yield line	
LIGHTING	
Lighting recommendations on roundabout	-
Lighting recommendations on approaches	-

Urban single lane roundabouts in the Netherlands

Design elements	Dimensions
GENERAL	
Maximum entering lanes per approach	1
Recommended maximum entry design speed	30 km/h
Recommended design speed on roundabout	30 km/h
Entries radial or tangential	Radial
Overturning of large goods vehicles	
Design vehicle	
CENTRAL PART	
Inscribed circle diameter	32 m
Circulatory carriageway width	5.50 m
Crossfall	Outward; 2-2.5%
CENTRAL ISLAND	
Truck apron present	Yes
Material truck apron	Cobble stones
Central island diameter (including truck apron)	21 m
Truck apron width	1.50 m
Height of central island	Minimum height 1.10 m
Landscaping	Optional, not limiting overview while driving on roundabout
Visibility requirements	On approach, central island should obstruct forward vision. On roundabout, drivers should have overview of entire roundabout. Height of central island of 1.10 m guarantees both requirements.
Island needs to be perfect circle?	Yes
APPROACHES/EXITS	
Entry width (no. of lanes)	4.00 m (1 lane) 3.50 m if no lorries present
Exit width (no. of lanes)	4.50 m (1 lane) 4.00 m if no lorries present
Entry radius	No bus route: 8 Bus route: 12 m
Exit radius	No bus route: 12 m Bus route: 15 m
Speed reduction on approach	
Entry flare permitted?	No
Length of entry flare	
Right turn bypass permitted?	Not recommended
CROSSING FACILITIES PEDESTRIANS/CYCLISTS	
Distance between crossing and outside circ. carriageway	5 m Cycle crossing preferably in red asphalt and raised (0.03 m)
DEFLECTION ISLAND	
Deflection island present	Yes (unless central island is smaller than recommended value)
Length of deflection island	14 to 15 m End of deflection island 1 m from outside circulatory carriageway width.
Width of deflection island	
ROAD MARKINGS	
Markings on roundabout	No
Marking on approach	No
Markings on yield line	Priority markings on entry. Broken line on exit.
LIGHTING	
Lighting recommendations on roundabout	Lighting columns around roundabout. Preferably 8 columns (one on each deflection island; one between each arm). Level of lighting at least 1.5 times the level on connecting roads.
Lighting recommendations on approaches	See above

The guidelines recommend the use of separate cycle paths with priority for cyclists on the crossings on connecting roads.

Urban double lane roundabouts in the Netherlands

Design elements	Dimensions				
GENERAL					
Maximum entering lanes per approach	2				
Recommended maximum entry design speed	40-45 km/h				
Recommended design speed on roundabout	40-45 km/h				
Entries radial or tangential	Radial				
Overturning of large goods vehicles					
Design vehicle					
CENTRAL PART	Different possible combinations				
Inscribed circle diameter	20m	25m	29m	33.50m	38m
Circulatory carriageway width	10m	9m	9m	8.50m	8m
Crossfall	Outward; 2-2.5%	Outward; 2-2.5%	Outward; 2-2.5%	Outward; 2-2.5%	Outward; 2-2.5%
CENTRAL ISLAND					
Truck apron present	No	No	No	No	No
Material truck apron					
Central island diameter (including truck apron)	10m*	16m*	20m	25m	30m
Truck apron width					
Height of central island	1.10m	1.10m	1.10m	1.10m	1.10m
Landscaping	Not limiting overview while driving on roundabout				
Visibility requirements	On approach central island should obstruct forward visibility; On circulatory cway, drivers should have overview of roundabout.				
Island needs to be perfect circle?	Yes	Yes	Yes	Yes	Yes
APPROACHES/EXITS					
Entry width (no. of lanes) 1 lane (designs with two lanes optional)	4.00 m 3.50 m if no lorries present	4.00 m 3.50 m if no lorries present	4.00 m 3.50 m if no lorries present	4.00 m 3.50 m if no lorries present	4.00 m 3.50 m if no lorries present
Exit width (no. of lanes) 1 lane (designs with two lanes optional, but not recommended)	4.50 m 4.00 m if no lorries present	4.50 m 4.00 m if no lorries present	4.50 m 4.00 m if no lorries present	4.50 m 4.00 m if no lorries present	4.50 m 4.00 m if no lorries present
Entry radius	12	12	12	12	12
Exit radius	15	15	15	15	15
Speed reduction on approach					
Entry flare permitted?	No				
Length of entry flare					
Right turn bypass permitted?	Not recommended				
CROSSING FACILITIES PEDESTRIANS/CYCLISTS					
Distance between crossing and outside circ. carriageway	5m. Cycle crossing preferably in red asphalt and raised (0.03 m)				
DEFLECTION ISLAND					
Deflection island present	Yes				
Length of deflection island	14 to 15m End of deflection island 1m from outside circulatory carriageway width				
Width of deflection island					
ROAD MARKINGS					
Markings on roundabout	Yes; lane separation markings				
Marking on approach	Lane markings in case of dual lane design				
Markings on yield line	Priority markings on entry. Broken line on exit.				
LIGHTING					
Lighting recommendations on roundabout	Lighting columns around roundabout. Preferably 8 columns (one on each deflection island; one between each arm). Level of lighting at least 1.5 times the level on connecting roads.				
Lighting recommendations on approaches	See above				

*= higher design speed

The guidelines recommend the use of separate cycle paths with priority for cyclists on the crossings on connecting roads.

Rural single lane roundabouts in the Netherlands

Design elements	Dimensions
GENERAL	
Maximum entering lanes per approach	1
Recommended maximum entry design speed	30-35 km/h
Recommended design speed on roundabout	30-35 km/h
Entries radial or tangential	Radial
Overturning of large goods vehicles	
Design vehicle	
CENTRAL PART	
Inscribed circle diameter	36 m
Circulatory carriageway width	5.25 m
Crossfall	Outward; 2–2.5%
CENTRAL ISLAND	
Truck apron present	Yes
Material truck apron	Cobble stones
Central island diameter (including truck apron)	25.50 m
Truck apron width	1.50 m
Height of central island	Minimum height 1.10 m
Landscaping	Optional, not limiting overview while driving on roundabout.
Visibility requirements	On approach, central island should obstruct forward vision. On roundabout, drivers should have overview of entire roundabout. Height of central island of 1.10 m guarantees both requirements.
Island needs to be perfect circle?	Yes
APPROACHES/EXITS	
Entry width (no. of lanes)	4.00 m (1 lane) 3.50 m if no lorries present
Exit width (no. of lanes)	4.50 m (1 lane) 4.00 m if no lorries present
Entry radius	No bus route: 8 Bus route: 12 m
Exit radius	No bus route: 12 m Bus route: 15 m
Speed reduction on approach	
Entry flare permitted?	No
Length of entry flare	
Right turn bypass permitted?	Not recommended
CROSSING FACILITIES PEDESTRIANS/CYCLISTS	
Distance between crossing and outside circ. carriageway	10 m
DEFLECTION ISLAND	
Deflection island present	Yes (unless central island is smaller than recommended value)
Length of deflection island	14 to 15 m End of deflection island 1 m from outside circulatory carriageway width.
Width of deflection island	
ROAD MARKINGS	
Markings on roundabout	No
Marking on approach	No
Markings on yield line	Priority markings on entry. Broken line on exit.
LIGHTING	
Lighting recommendations on roundabout	Lighting columns around roundabout. Preferably 8 columns (one on each deflection island; one between each arm). Level of lighting at least 1.5 times the level on connecting roads.
Lighting recommendations on approaches	See above

The guidelines recommend the use of separate cycle paths without priority for cyclists on the crossings on connecting roads (cyclists have to give priority to vehicles on approaches).

Rural double lane roundabouts in the Netherlands

Design elements	Dimensions				
GENERAL					
Maximum entering lanes per approach	2				
Recommended maximum entry design speed	40-45 km/h				
Recommended design speed on roundabout	40-45 km/h				
Entries radial or tangential	Radial				
Overturning of large goods vehicles					
Design vehicle					
CENTRAL PART	Different possible combinations				
Inscribed circle diameter	20m	25m	29m	33.50m	38m
Circulatory carriageway width	10m	9m	9m	8.50m	8m
Crossfall	outward; 2-2.5%	outward; 2-2.5%	outward; 2-2.5%	outward; 2-2.5%	outward; 2-2.5%
CENTRAL ISLAND					
Truck apron present	No	No	No	No	No
Material truck apron					
Central island diameter (including truck apron)	10m*	16m*	20m	25m	30m
Truck apron width					
Height of central island	1.10m	1.10m	1.10m	1.10m	1.10m
Landscaping	Not limiting overview while driving on roundabout				
Visibility requirements	On approach central island should obstruct forward visibility; On circulatory cway, drivers should have overview of roundabout.				
Island needs to be perfect circle?	Yes	Yes	Yes	Yes	Yes
APPROACHES/EXITS					
Entry width (no. of lanes) 1 lane (designs with two lanes optional)	4 m 3.50 m if no lorries present	4 m 3.50 m if no lorries present	4 m 3.50 m if no lorries present	4 m 3.50 m if no lorries present	4 m 3.50 m if no lorries present
Exit width (no. of lanes) 1 lane (designs with two lanes optional, but not recommended)	4.50 m 4 m if no lorries present	4.50 m 4 m if no lorries present	4.50 m 4 m if no lorries present	4.50 m 4 m if no lorries present	4.50 m 4 m if no lorries present
Entry radius	12	12	12	12	12
Exit radius	15	15	15	15	15
Speed reduction on approach					
Entry flare permitted?	No				
Length of entry flare					
Right turn bypass permitted?	Not recommended				
CROSSING FACILITIES PEDESTRIANS/CYCLISTS					
Distance between crossing and outside circ. carriageway	10 m				
DEFLECTION ISLAND					
Deflection island present	Yes				
Length of deflection island	14 to 15 m End of deflection island 1m from outside circulatory carriageway width				
Width of deflection island					
ROAD MARKINGS					
Markings on roundabout	Yes; lane separation markings.				
Marking on approach	Lane markings in case of dual lane design.				
Markings on yield line	Priority markings on entry Broken line on exit.				
LIGHTING					
Lighting recommendations on roundabout	Lighting columns around roundabout. 8 columns (one on each deflection island; one between each arm). Level of lighting at least 1.5 times the level on connecting roads.				
Lighting recommendations on approaches	See above.				

*= higher design speed

The guidelines recommend the use of separate cycle paths without priority for cyclists on the crossings on connecting roads (cyclists have to give priority to vehicles on approaches).

A.4 Norway

The information is based on summaries and articles on the Norwegian guidelines (Giaever, 1992, Seim, 1991). There were no separate design recommendations for urban or rural areas, nor was there any guidance on cyclist provision.

Urban mini-roundabouts in Norway

Design elements	**Dimensions**
GENERAL	
Maximum entering lanes per approach	
Recommended maximum entry design speed	
Recommended design speed on roundabout	
Entries radial or tangential	Radial
Overturning of large goods vehicles	
Design vehicle	
CENTRAL PART	
Inscribed circle diameter	< 25 m
Circulatory carriageway width	
Crossfall	
CENTRAL ISLAND	
Truck apron present	
Material truck apron	
Central island diameter (including truck apron)	1.5 – 4 m
Truck apron width	
Height of central island	
Landscaping	
Visibility requirements	
Island needs to be perfect circle	
APPROACHES/EXITS	
Entry width (no. of lanes)	
Exit width (no. of lanes)	
Entry radius	
Exit radius	
Speed reduction on approach	
Entry flare permitted?	
Length of entry flare	
Right turn bypass permitted?	
CROSSING FACILITIES PEDESTRIANS/CYCLISTS	
Distance between crossing and outside circ. carriageway	10 – 12 m
DEFLECTION ISLAND	
Deflection island present	
Length of deflection island	
Width of deflection island	
ROAD MARKINGS	
Markings on roundabout	
Marking on approach	
Markings on yield line	
LIGHTING	
Lighting recommendations on roundabout	
Lighting recommendations on approaches	

Urban and rural single lane roundabouts in Norway

Design elements	Dimensions		
	Small	**Medium**	**Large**
GENERAL			
Maximum entering lanes per approach			
Recommended maximum entry design speed			
Recommended design speed on roundabout			
Entries radial or tangential	Tangential	Tangential	Tangential
Overturning of large goods vehicles			
Design vehicle			
CENTRAL PART			
Inscribed circle diameter	26 – 30 m	31 – 45 m	-
Circulatory carriageway width			
Crossfall			
CENTRAL ISLAND			
Truck apron present			
Material truck apron			
Central island diameter (including truck apron)	> 5 m	> 10 m	> 25 m
Truck apron width			
Height of central island			
Landscaping			
Visibility requirements			
Island needs to be perfect circle			
APPROACHES/EXITS			
Entry width (no. of lanes)			
Exit width (no. of lanes)			
Entry radius	10 – 100 m (typically 20 m)	10 – 100 m (typically 20 m)	10 – 100 m (typically 20 m)
Exit radius	20 – 100 m (typically 40 m)	20 – 100 m (typically 40 m)	20 – 100 m (typically 40 m)
Speed reduction on approach			
Entry flare permitted?			
Length of entry flare			
Right turn bypass permitted?			
CROSSING FACILITIES PEDESTRIANS/CYCLISTS			
Distance between crossing and outside circ. carriageway	Urban: > 5 m Rural: 10 – 12 m	Urban: > 5 m Rural: 10 – 12 m	Urban: > 5 m Rural: 10 – 12 m
DEFLECTION ISLAND			
Deflection island present	Yes	Yes	Yes
Length of deflection island			
Width of deflection island			
ROAD MARKINGS			
Markings on roundabout	No (unless there are 3 or more approach lanes)	No (unless there are 3 or more approach lanes)	No (unless there are 3 or more approach lanes)
Marking on approach			
Markings on yield line			
LIGHTING			
Lighting recommendations on roundabout			
Lighting recommendations on approaches			

Urban and rural double lane roundabouts in Norway

Design elements	Dimensions
GENERAL	
Maximum entering lanes per approach	
Recommended maximum entry design speed	
Recommended design speed on roundabout	
Entries radial or tangential	Tangential
Overturning of large goods vehicles	
Design vehicle	
CENTRAL PART	
Inscribed circle diameter	40 – 45 m
Circulatory carriageway width	
Crossfall	
CENTRAL ISLAND	
Truck apron present	
Material truck apron	
Central island diameter (including truck apron)	
Truck apron width	
Height of central island	
Landscaping	
Visibility requirements	
Island needs to be perfect circle	
APPROACHES/EXITS	
Entry width (no. of lanes)	
Exit width (no. of lanes)	
Entry radius	10 – 100 m (typically 20 m)
Exit radius	20 – 100 m (typically 40 m)
Speed reduction on approach	
Entry flare permitted?	
Length of entry flare	
Right turn bypass permitted?	
CROSSING FACILITIES PEDESTRIANS/CYCLISTS	
Distance between crossing and outside circ. carriageway	10 – 12 m
DEFLECTION ISLAND	
Deflection island present	Yes
Length of deflection island	
Width of deflection island	
ROAD MARKINGS	
Markings on roundabout	No (unless there are 3 or more approach lanes)
Marking on approach	
Markings on yield line	
LIGHTING	
Lighting recommendations on roundabout	
Lighting recommendations on approaches	

A.5 Sweden

The information is based on VTI research reports describing differences between Swedish design guidelines and those in Denmark, France, the Netherlands, Norway, UK and Germany (Brüde and Larsson, 1999, Herland and Helmers, 2002).

Separate cycle paths with cycle crossings are the most common form of provision for cyclists in Sweden.

Urban mini-roundabouts in Sweden

Design elements	Dimensions
GENERAL	
Maximum entering lanes per approach	1
Recommended maximum entry design speed	
Recommended design speed on roundabout	
Entries radial or tangential	Radial entry; tangential exit
Overturning of large goods vehicles	
Design vehicle	
CENTRAL PART	
Inscribed circle diameter	28 m
Circulatory carriageway width	12 m
Crossfall	
CENTRAL ISLAND	
Truck apron present	
Material truck apron	
Central island diameter (including truck apron)	4
Truck apron width	
Height of central island	
Landscaping	
Visibility requirements	
Island needs to be perfect circle	
APPROACHES/EXITS	
Entry width (no. of lanes)	≥ 3.50 m (1)
Exit width (no. of lanes)	≥ 3.50 / 4.50 m (1)
Entry radius	10 – 25 m (8 – 12 m for speed reducing entries)
Exit radius	100 – 200 m
Speed reduction on approach	Optional
Entry flare permitted?	
Length of entry flare	
Right turn bypass permitted?	
CROSSING FACILITIES PEDESTRIANS/CYCLISTS	
Distance between crossing and outside circ. carriageway	
DEFLECTION ISLAND	
Deflection island present	Yes
Length of deflection island	
Width of deflection island	
ROAD MARKINGS	
Markings on roundabout	
Marking on approach	
Markings on yield line	
LIGHTING	
Lighting recommendations on roundabout	
Lighting recommendations on approaches	

Urban and rural roundabouts (single and double lane) in Sweden

Design elements	Dimensions				
GENERAL					
Maximum entering lanes per approach					
Recommended maximum entry design speed					
Recommended design speed on roundabout					
Entries radial or tangential					
Overturning of large goods vehicles					
Design vehicle					
	“Small”		“Normal”		
CENTRAL PART					
Inscribed circle diameter	30.8 m	36 m	53 m	71 m	90 m
Circulatory carriageway width	10.4 m	8 m	6.5 m	5.5 m	5 m
Crossfall					
CENTRAL ISLAND					
Truck apron present	No	No	No	No	No
Material truck apron					
Central island diameter (including truck apron)	10 m	20 m	40 m	60 m	80 m
Truck apron width					
Height of central island					
Landscaping					
Visibility requirements					
Island needs to be perfect circle					
APPROACHES/EXITS					
Entry width (no. of lanes)	3.50 m (1 lane); 7.00 m (2 lanes)				
Exit width (no. of lanes)	3.50 / 4.50 m (1 lane); 7.00 m (2 lanes)				
Entry radius	10 – 25 m (8 – 12 m for speed reducing entries)				
Exit radius	100 – 200 m				
Speed reduction on approach	Optional (successive curves)				
Entry flare permitted?					
Length of entry flare					
Right turn bypass permitted?					
CROSSING FACILITIES PEDESTRIANS/CYCLISTS					
Distance between crossing and outside circ. carriageway					
DEFLECTION ISLAND					
Deflection island present	Yes				
Length of deflection island					
Width of deflection island					
ROAD MARKINGS					
Markings on roundabout					
Marking on approach					
Markings on yield line					
LIGHTING					
Lighting recommendations on roundabout					
Lighting recommendations on approaches					

A.6 Denmark

Only very limited information on the design of an urban single lane roundabout in Denmark was found (Kjemtrup, 1992*)*. The recommended provision for cyclists was for a cycle lane at least 1.70m wide on the circulatory carriageway.

A.7 United States

The use of roundabouts has become popular in the US only recently. Some states have their own design guidelines and the Federal Highway Administration has produced an informational guide on roundabouts (FHA, 2000). The information and design recommendations are largely based on experience elsewhere. The information in this section is based on the FHA guide.

Typical pedal cycle treatment in the design recommendations consists of ending the cycle lane before the roundabout, leading cyclists onto an (extended) footway and having shared cyclist/pedestrian crossings. Cycle lanes within the circulatory carriageway are strongly advised against, for safety reasons.

The recommended design for mini-roundabouts, with typical traffic volumes up to 10,000 vehicles per day, is based on the German design, with some influence from the United Kingdom.

Compact 4-arm urban roundabouts have typical flows of 15,000 vpd. Their design is based on roundabouts in Germany and other northern European countries. Urban single lane roundabouts have typical volumes of 20,000 vpd and their recommended design is similar to those in Australia and France. The recommended design for urban double lane roundabouts is based on the design used in the UK, with influences from Australia and France, as is the design of rural roundabouts.

Urban mini-roundabouts in the USA

Design elements	**Dimensions**
GENERAL	
Maximum entering lanes per approach	1
Recommended maximum entry design speed	25 km/h
Recommended design speed on roundabout	-
Entries radial or tangential	Radial
Overturning of large goods vehicles	-
Design vehicle	Single-unit truck
CENTRAL PART	
Inscribed circle diameter	13 m to 25 m
Circulatory carriageway width	Calculated by vehicle path curvature
Crossfall	2% outward
CENTRAL ISLAND	
Truck apron present	Not relevant
Material truck apron	Not relevant
Central island diameter (including truck apron)	Minimum of 4 m Diameter calculated by vehicle path curvature.
Truck apron width	
Height of central island	Maximum 125 mm central island is mountable
Landscaping	-
Visibility requirements	-
Island needs to be perfect circle?	Yes
APPROACHES/EXITS	
Entry width (no. of lanes)	-
Exit width (no. of lanes)	-
Entry radius	Calculated
Exit radius	Calculated
Speed reduction on approach	-
Entry flare permitted?	Not relevant
Length of entry flare	Not relevant
Right turn bypass permitted?	Not relevant
CROSSING FACILITIES PEDESTRIANS/CYCLISTS	
Distance between crossing and outside circ. carriageway	7.50 m
DEFLECTION ISLAND	
Deflection island present	Yes; raised if possible. Crosswalk cut if raised. Striped or mountable.
Length of deflection island	Minimum length 15 m Offset 0.5-1.0 m
Width of deflection island	
ROAD MARKINGS	
Markings on roundabout	No
Marking on approach	-
Markings on yield line	Yield lines just outside of the swept path of the largest expected vehicle
LIGHTING	
Lighting recommendations on roundabout	Recommended. Illumination on outside of roundabout, preferably on nose of deflection island. Level of illumination should be approx. equal to sum of illumination levels of intersecting roads.
Lighting recommendations on approaches	

Urban single lane roundabouts in the USA

Design elements	**Dimensions**	
	Urban Compact	**Urban standard**
GENERAL		
Maximum entering lanes per approach	1	1
Recommended maximum entry design speed	25 km/h	35 km/h
Recommended design speed on roundabout	-	-
Entries radial or tangential	Radial	Radial
Overturning of large goods vehicles	-	-
Design vehicle	Single-unit truck/bus	WB-15
CENTRAL PART		
Inscribed circle diameter	25 m to 30 m	30 m to 40 m
Circulatory carriageway width	Calculated	Calculated
Crossfall	Outward 2%	Outward 2%
CENTRAL ISLAND		
Truck apron present	Typically required.	Preferably not
Material truck apron	Coloured and/or textured material	
Central island diameter (including truck apron)	Calculated	Calculated
Truck apron width	Between 1 and 4 m	
Height of central island	Non-mountable central island.	
Landscaping	Optional; no hard obstacles directly facing entry.	Optional; no hard obstacles directly facing entry
Visibility requirements	Stopping sight distance; intersection sight distance.	Stopping sight distance; intersection sight distance.
Island needs to be perfect circle?	Yes	Yes
APPROACHES/EXITS		
Entry width (no. of lanes)	-	-
Exit width (no. of lanes)	-	-
Entry radius	Calculated	Calculated approx. 10 to 30 m
Exit radius	Calculated	Calculated not less than 15 m (no large veh: 10-12m)
Speed reduction on approach	-	-
Entry flare permitted?	Not relevant	Not relevant
Length of entry flare	Not relevant	Not relevant
Right turn bypass permitted?	Not relevant	Preferably not
CROSSING FACILITIES PEDESTRIANS/CYCLISTS		
Distance between crossing and outside circ. carriageway	7.50 m	7.50 m
DEFLECTION ISLAND		
Deflection island present	Yes; raised with crosswalk cut	Yes; raised with crosswalk cut
Length of deflection island	Minimum length 15 m offset 0.5-1.0 m	Minimum length 15 m offset 0.5-1.0 m
Width of deflection island		
ROAD MARKINGS		
Markings on roundabout	No	No
Marking on approach		-
Markings on yield line	Yield lines just outside swept path of largest expected vehicle	Yield lines just outside swept path of largest expected vehicle
LIGHTING		
Lighting recommendations on roundabout	Recommended. Illumination on outside of roundabout, preferably on nose of deflection island. Level of illumination should be approx. equal to sum of illumination levels of intersecting roads.	Recommended. Illumination on outside of roundabout, preferably on nose of deflection island. Level of illumination should be approx. equal to sum of illumination levels of intersecting roads.
Lighting recommendations on approaches	-	-

Urban double lane roundabouts in the USA

Design elements	Dimensions
GENERAL	
Maximum entering lanes per approach	2
Recommended maximum entry design speed	40 km/h
Recommended design speed on roundabout	-
Entries radial or tangential	Radial
Overturning of large goods vehicles	-
Design vehicle	WB-15
CENTRAL PART	
Inscribed circle diameter	45 m to 55 m
Circulatory carriageway width	Calculated
Crossfall	Outward 2%
CENTRAL ISLAND	
Truck apron present	No
Material truck apron	
Central island diameter (including truck apron)	Calculated
Truck apron width	
Height of central island	Non-mountable central island
Landscaping	Optional; no hard obstacles directly facing entry
Visibility requirements	Stopping sight distance; intersection sight distance
Island needs to be perfect circle?	Yes
APPROACHES/EXITS	
Entry width (no. of lanes)	-
Exit width (no. of lanes)	-
Entry radius	Calculated
Exit radius	Calculated
Speed reduction on approach	-
Entry flare permitted?	Yes
Length of entry flare	25 m
Right turn bypass permitted?	Preferably not
CROSSING FACILITIES PEDESTRIANS/CYCLISTS	
Distance between crossing and outside circ. carriageway	7.50 m
DEFLECTION ISLAND	
Deflection island present	Yes; raised with crosswalk cut
Length of deflection island	Minimum length 15 m offset 0.5-1.0 m
Width of deflection island	
ROAD MARKINGS	
Markings on roundabout	No
Marking on approach	-
Markings on yield line	Yield lines just outside swept path of largest expected vehicle
LIGHTING	
Lighting recommendations on roundabout	Recommended. Illumination on outside of roundabout, preferably on nose of deflection island. Level of illumination should be approx. equal to sum of illumination levels of intersecting roads.
Lighting recommendations on approaches	-

Rural single lane roundabouts in the USA

Design elements	Dimensions
GENERAL	
Maximum entering lanes per approach	1
Recommended maximum entry design speed	40 km/h
Recommended design speed on roundabout	-
Entries radial or tangential	Radial
Overturning of large goods vehicles	-
Design vehicle	WB-20
CENTRAL PART	
Inscribed circle diameter	35 m to 40 m
Circulatory carriageway width	Calculated
Crossfall	Outward 2%
CENTRAL ISLAND	
Truck apron present	Preferably not
Material truck apron	
Central island diameter (including truck apron)	Calculated
Truck apron width	
Height of central island	
Landscaping	Optional; no hard obstacles directly facing entry.
Visibility requirements	-
Island needs to be perfect circle?	Yes
APPROACHES/EXITS	
Entry width (no. of lanes)	-
Exit width (no. of lanes)	-
Entry radius	Calculated
Exit radius	Calculated Not less than 15 m (no large veh.: 10-12m)
Speed reduction on approach	Successive curves on approach
Entry flare permitted?	Not relevant
Length of entry flare	Not relevant
Right turn bypass permitted?	Preferably not
CROSSING FACILITIES PEDESTRIANS/CYCLISTS	
Distance between crossing and outside circ. carriageway	7.50 m
DEFLECTION ISLAND	
Deflection island present	Yes; raised and extended, with crosswalk cut
Length of deflection island	Minimum length 15 m offset 0.5-1.0 m
Width of deflection island	
ROAD MARKINGS	
Markings on roundabout	No
Marking on approach	
Markings on yield line	Yield lines just outside swept path of largest expected vehicle
LIGHTING	
Lighting recommendations on roundabout	Recommended. Illumination on outside of roundabout, preferably on nose of deflection island. Level of illumination should be approx. equal to sum of illumination levels of intersecting roads.
Lighting recommendations on approaches	-

Rural double lane roundabouts in the USA

Design elements	Dimensions
GENERAL	
Maximum entering lanes per approach	2
Recommended maximum entry design speed	50 km/h
Recommended design speed on roundabout	-
Entries radial or tangential	Radial
Overturning of large goods vehicles	-
Design vehicle	WB-20
CENTRAL PART	
Inscribed circle diameter	55 m to 60 m
Circulatory carriageway width	Calculated
Crossfall	Outward 2%
CENTRAL ISLAND	
Truck apron present	No.
Material truck apron	
Central island diameter (including truck apron)	Calculated
Truck apron width	
Height of central island	
Landscaping	Optional; no hard obstacles directly facing entry
Visibility requirements	Stopping sight distance; intersection sight distance.
Island needs to be perfect circle?	Yes
APPROACHES/EXITS	
Entry width (no. of lanes)	-
Exit width (no. of lanes)	-
Entry radius	Calculated
Exit radius	Calculated
Speed reduction on approach	Successive curves on approach
Entry flare permitted?	Yes
Length of entry flare	40 m
Right turn bypass permitted?	Preferably not
CROSSING FACILITIES PEDESTRIANS/CYCLISTS	
Distance between crossing and outside circ. carriageway	7.50 m
DEFLECTION ISLAND	
Deflection island present	Yes; raised and extended, with crosswalk cut
Length of deflection island	Minimum length 15 m offset 0.5-1.0 m
Width of deflection island	
ROAD MARKINGS	
Markings on roundabout	No
Marking on approach	-
Markings on yield line	Yield lines just outside swept path of largest expected vehicle.
LIGHTING	
Lighting recommendations on roundabout	Recommended. Illumination on outside of roundabout, preferably on nose of deflection island. Level of illumination should be approx. equal to sum of illumination levels of intersecting roads.
Lighting recommendations on approaches	-

A.8 Australia

The Australian guidelines (AUSTROADS, 1993) do not provide separate recommendations for urban and rural situations and give limited guidance on provision for cyclists. They are an update and major revision of the 1986 NAASRA guidelines. Considerable detail is provided on analytical methods and on the use of the computer package SIDRA for capacity calculations.

Urban and rural single lane roundabouts in Australia

Design elements	Dimensions	
	Urban compact	Arterials
GENERAL		
Maximum entering lanes per approach		
Recommended maximum entry design speed		No more than 10 – 15 km/h. than speed on roundabout
Recommended design speed on roundabout	25 km/h.	< 50 km/h
Entries radial or tangential	Tangential	Tangential
Overturning of large goods vehicles		
Design vehicle	Single unit truck/ bus	Similar as used on comparable junctions
CENTRAL PART		
Inscribed circle diameter	To be determined by designer. Typically ± 15 m	To be determined by designer.
Circulatory carriageway width	To be determined by designer. Typically ± 4.5 m	4.6 – 7.6 m
Crossfall	Outward 2.5%	Outward 2.5%
CENTRAL ISLAND		
Truck apron present	Yes	Only if over-dimensional vehicles present
Material truck apron	Semi mountable	Semi mountable
Central island diameter (including truck apron)	5 – 8 m	> 5 m; preferably > 10 m
Truck apron width	To be determined by designer.	To be determined by designer.
Height of central island		
Landscaping	Optional	Optional
Visibility requirements	As normal junctions.	1. Stopping sight 2. From yield line unobstructed sight over first quarter of roundabout (to the right) 3. Preferably see vehicle on approach arm to the right at longer distance before roundabout.
Island needs to be perfect circle	Yes	Yes
APPROACHES/EXITS		
Entry width (no. of lanes)	To be determined by designer.	3.4 – 4.0 m (if lane is within kerbs 5m)
Exit width (no. of lanes)	To be determined by designer.	3.4 – 4.0 m
Entry radius	To be determined by designer.	To be determined by designer.
Exit radius	To be determined by designer.	“As easy to negotiate as practicable”.
Speed reduction on approach		
Entry flare permitted?		Yes
Length of entry flare		
Right turn bypass permitted?		Yes
CROSSING FACILITIES PEDESTRIANS/CYCLISTS		
Distance between crossing and outside circ. carriageway	6 m (at informal crossing); 6 – 12 m (at Zebra crossings)	6m (at informal crossing); 6 – 12m (at Zebra crossings)
DEFLECTION ISLAND		
Deflection island present	Yes	Yes
Length of deflection island		
Width of deflection island		
ROAD MARKINGS		
Markings on roundabout		
Marking on approach		
Markings on yield line	Broken yield line on entry. No markings on exit.	Broken yield line on entry. No markings on exit.
LIGHTING		
Lighting recommendations on roundabout	Yes (not specified)	Yes (not specified)
Lighting recommendations on approaches	Yes (not specified)	Yes (not specified)

Urban and rural double (or more than 2) lane roundabouts in Australia

Design elements	**Dimensions**
GENERAL	
Maximum entering lanes per approach	
Recommended maximum entry design speed	No more than 10 – 15 km/h. than speed on roundabout
Recommended design speed on roundabout	< 50 km/h
Entries radial or tangential	Tangential
Overturning of large goods vehicles	
Design vehicle	Similar as used on comparable junctions
CENTRAL PART	
Inscribed circle diameter	To be determined by designer.
Circulatory carriageway width	8.4 – 10.3 m (2 lanes); 12.2 – 13.5 m (3 lanes)
Crossfall	Outward 2.5%
CENTRAL ISLAND	
Truck apron present	Only if over-dimensional vehicles present
Material truck apron	Semi mountable
Central island diameter (including truck apron)	> 5 m; preferably > 10 m
Truck apron width	To be determined by designer.
Height of central island	
Landscaping	Optional
Visibility requirements	1. Stopping sight 2. From yield line unobstructed sight over first quarter of roundabout (to the right) 3. Preferably see vehicle on approach arm to the right at longer distance before roundabout.
Island needs to be perfect circle	Yes
APPROACHES/EXITS	
Entry width (no. of lanes)	3.4 – 4.0 m per lane
Exit width (no. of lanes)	3.4 – 4 m per lane
Entry radius	> 30 m
Exit radius	“As easy to negotiate as practicable”.
Speed reduction on approach	
Entry flare permitted?	Yes
Length of entry flare	
Right turn bypass permitted?	Yes
CROSSING FACILITIES PEDESTRIANS/CYCLISTS	
Distance between crossing and outside circ. carriageway	6 m (at informal crossing); 6 – 12 m (at Zebra crossings)
DEFLECTION ISLAND	
Deflection island present	Yes
Length of deflection island	
Width of deflection island	
ROAD MARKINGS	
Markings on roundabout	
Marking on approach	
Markings on yield line	Broken yield line on entry. No markings on exit.
LIGHTING	
Lighting recommendations on roundabout	Yes (not specified)
Lighting recommendations on approaches	Yes (not specified)

Appendix B. Accident tabulations for UK roundabouts

Table B1: Accidents and accident frequency by number of arms (1999 to 2003)

		Number of accidents					
No. of arms	No. of sites	Fatal	Serious	Slight	Total	Accident frequency	Severity (% fatal and serious)
3	326	6	114	1173	1293	0.79	9.3
4	649	16	399	5400	5815	1.79	7.1
5	157	13	189	2654	2856	3.66	7.1
6	30	4	42	846	892	5.95	5.2
All	1162	39	744	10073	10856	1.87	7.2

Table B2: Accidents and accident frequency at roundabouts on dual-carriageway roads by number of arms (1999 to 2003)

		Number of accidents					
No. of arms	No. of sites	Fatal	Serious	Slight	Total	Accident frequency	Severity (% fatal and serious)
3	59	3	35	341	379	1.28	10.0
4	132	3	101	1645	1749	2.65	5.9
5	44	3	60	772	835	3.80	7.5
6	9	1	13	194	208	4.62	6.7
All	244	10	209	2952	3171	2.60	6.9

Table B3: Accidents and accident frequency at roundabouts on single-carriageway roads by number of arms (1999 to 2003)

		Number of accidents					
No. of arms	No. of sites	Fatal	Serious	Slight	Total	Accident frequency	Severity (% fatal and serious)
3	255	2	69	727	798	0.63	8.9
4	457	8	219	2233	2460	1.08	9.2
5	73	1	44	584	629	1.72	7.2
6	7	0	3	71	74	2.11	4.1
All	792	11	335	3615	3961	1.00	8.7

Table B4: Accidents and accident frequency at grade separated roundabouts by number of arms (1999 to 2003)

No. of arms	No. of sites	Number of accidents Fatal	Serious	Slight	Total	Accident frequency	Severity (% fatal and serious)
3	8	1	10	97	108	2.70	10.2
4	60	5	79	1520	1604	5.35	5.2
5	36	9	85	1287	1381	7.67	6.8
6	14	3	26	581	610	8.71	4.8
All	118	18	200	3485	3703	6.28	5.9

Table B5: Accidents, accident frequency and accident rate at roundabouts with flow data, by number of arms (1999 to 2003)

No. of arms	No. of sites	Number of accidents Fatal	Serious	Slight	Total	Severity (% fatal and serious)	Accident frequency	Accident rate
3	11	0	6	121	127	4.7	2.31	22.2
4	29	2	42	464	508	8.7	3.50	36.2
5	4	0	4	130	134	3.0	6.70	50.6
All	44	2	52	715	769	7.0	3.51	7.1

Table B6: Accidents by number of vehicles involved (1999 to 2003)

No. of vehicles	1	2	3	4	5	6	Total
No. of accidents	1605	8602	568	70	8	3	10856
% of accidents	14.8%	79.2%	5.2%	0.6%	0.1%	0.0%	100.0%

Table B7: Accidents by type of vehicle involved (1999 to 2003)

	Number of accidents Fatal	Slight	Serious	Total	% of Accidents	Severity
Pedal cycles	2	782	80	864	8.0%	9.5%
Pedestrians	4	233	64	301	2.8%	22.6%
Motorcycles	11	1265	291	1567	14.4%	19.3%
Cars and taxis	23	7822	480	8325	76.7%	6.0%
Public Service Vehicles	2	259	20	281	2.6%	7.8%
Light goods vehicles	2	660	37	699	6.4%	5.6%
Heavy goods vehicles	8	934	73	1015	9.3%	8.0%

Table B8: Accidents by year (1999 to 2003)

Year	**1999**	**2000**	**2001**	**2002**	**2003**
Number of accidents	2251	2285	2147	2076	2097
Ratio	1.04	1.05	0.99	0.96	0.97

Table B9: Accidents by day of week (1999 to 2003)

Day	Number of accidents	Ratio
Monday	1579	1.02
Tuesday	1629	1.05
Wednesday	1604	1.03
Thursday	1636	1.05
Friday	1719	1.11
Saturday	1410	0.91
Sunday	1279	0.82

Table B10: Accidents by month of year (1999 to 2003)

Month	Number of accidents	Ratio	National ratio (2003)
January	874	0.97	0.97
February	811	0.90	0.90
March	786	0.87	0.92
April	835	0.92	0.93
May	921	1.02	1.01
June	883	0.98	1.01
July	964	1.07	1.05
August	906	1.00	0.99
September	965	1.07	1.05
October	1007	1.11	1.10
November	1017	1.12	1.08
December	887	0.98	1.00

Table B11: Accidents by hour of day (1999 to 2003)

Time period	Number of accidents	Ratio	National ratio (2003)
00 - 02	200	0.22	0.38
02 - 04	106	0.12	0.24
04 - 06	121	0.13	0.13
06 - 08	720	0.80	0.58
08 - 10	1399	1.55	1.33
10 - 12	1229	1.36	1.16
12 - 14	1459	1.61	1.50
14 - 16	1443	1.60	1.64
16 - 18	1834	2.03	2.00
18 - 20	1257	1.39	1.45
20 - 22	616	0.68	0.90
22 - 00	472	0.52	0.68

Abstract

Roundabouts have been a key form of junction in the UK for many years. They are used on all classes of road in both urban and rural areas for the efficient and safe control of traffic, particularly where side road flows are high. Roundabouts are heavily used throughout the UK's trunk and principal road network, as well as on local authority roads.

The report presents an international review of roundabout design standards and guidelines that was undertaken to inform the revision the UK Geometric Design Standard for Roundabouts (TD 16/93 at the time of this review). Provision for pedestrians and cyclists was of particular concern.

A design hierarchy for roundabouts is proposed for the revised Standard, to depend on road type, whether the speed limits on the approach roads exceed 40mph and on the levels of vehicle and non-motorised user flow. A "compact" (continental-style) roundabout is proposed for low flow roads, with single lane entries, exits and circulatory carriageway. In urban areas, this would have tighter geometry than normal roundabouts, and outward crossfall.