THE HIGHWAYS AGENCY

TD 16/93

THE SCOTTISH OFFICE DEVELOPMENT DEPARTMENT

THE WELSH OFFICE
Y SWYDDFA GYMREIG

THE DEPARTMENT OF THE ENVIRONMENT FOR NORTHERN IRELAND

Geometric Design of Roundabouts

Summary: This document gives advice and standards for the geometric design of roundabouts with regard to traffic operation and safety. Amendments and additions have been made to reflect current good practice in aspects such as entry path curvature assessments, geometry of entries, segregated left turn lanes, over capacity in early years, and speed reducing measures at mini roundabouts.

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SECTION 2 JUNCTIONS

PART 3

TD 16/93

GEOMETRIC DESIGN OF ROUNDABOUTS

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1. INTRODUCTION

General

1.1 The treatment of roundabout layout design has been the subject of a recent study which reviewed Standard TD 16/84 and Advice Note TA 42/84 on the Geometric Design of Roundabouts. It made recommendations on amendments and additions to those documents based on current good practice.

1.2 Arising out of the study this document now provides details of the latest requirements and recommendations on general design principles and safety aspects of design.

1.3 This document supersedes Standard TD 16/84 and Advice Note TA 42/84.

1.4 Guidance on the most appropriate form of junction is given in TA 30 (DMRB 5.1).

Scope

1.5 This document defines three main types of roundabout and their derivatives for application to new and improved junctions on trunk roads. They have application for use on other roads.

1.6 Requirements are defined in relation to the size of roundabouts, effect of approach speed, visibility, entry width, entry deflection and the circulatory carriageway.

1.7 Recommendations are given on the siting of roundabouts in urban and rural areas, geometric design, crossfalls and segregated left turning lanes.

1.8 The first major change is the amendment to the definition of entry path curvature. This ensures that a radius of curvature greater than 100m cannot now be achieved by driving the straightest path on the approach and through the junction by selecting the outer lane on approach at certain junctions (see paras 7.25 - 7.32). The second major change is that the visibility requirements on the circulatory carriageway are mandatory (see para 7.45).

1.9 Other significant changes include the following:-

i. the deletion of the raised profile to Subsidiary Traffic Deflection Islands;

ii. emphasis of the importance of approach curvature and its effect on safety;

iii. geometric changes to entries;

iv. means of dealing with over capacity in early years of operation;

v. advice on segregated left turn lanes;

vi. advice on traffic speed reducing methods at mini-roundabouts.

Implementation

1.10 This document should be used forthwith on all schemes for the construction, improvement and maintenance of trunk roads including motorways, currently being prepared provided that, in the opinion of the Overseeing Department, this would not result in significant additional expense or delay progress. Design Organisations should confirm its application to particular schemes with the Overseeing Department.

General Principles

1.11 The principal objective of roundabout design is to secure the safe interchange of traffic between crossing traffic streams with minimum delay. This is achieved by a combination of geometric layout features that, ideally, are matched to the volumes of traffic in the traffic streams, their speed, and to any locational constraints that apply.

1.12 There are two broad regimes of roundabout operation. The first occurs in urban areas with high peak flows, often with marked tidal variations and physical restrictions on the space available. The second regime occurs in rural areas and is characterised by high approach speeds, low tidal variation and few physical constraints.

1.13 Entry width is an important feature that determines entry capacity and it often needs to be larger in urban situations than in rural cases. On the other hand the most important determinant of safety is vehicle deflection imposed at entry because this governs the speed of vehicles through the junction. It is particularly important whenever approach speeds are high. Entry deflection is related to the entry path curvature and limiting this radius of curvature in the vicinity of the entry to 100m maximum ensures that sufficient deflection will be undergone by entering vehicles to limit through speeds.

1.14 The characteristics of roundabout accidents and their frequencies in relation to geometric layout design and traffic flows are reported in TRL Report LR 1120 "Accidents at Four-Arm Roundabouts". The relationships derived in this report provide insights into the way various aspects of design interact to influence the types and frequencies of accidents at roundabouts. These relationships therefore, constitute the fundamentals of design for safety. As relationships between aspects of design are not always mutually compatible, minimising the likely incidence of a particular type of accident may increase the potential for another. Design, therefore is a trade-off between operational efficiency, minimising delays at the junction, and various safety aspects within whatever location constraints apply. The latter are often the dominating factor when designing improvements to an existing junction, particularly in urban areas. The accident prediction model given in LR 1120 can be used to compare the safety characteristics of alternative designs. This model has now been incorporated into the TRL program ARCADY/3 - see TA 44 (DMRB 5.1.1).

1.15 Consideration of the need for, and layout of traffic signs and road markings should be an integral part of the design process. (Refer to para 7.77 and DMRB 8.2).

1.16 The provision of road lighting at roundabouts should normally be regarded as an essential safety requirement (DMRB 8.3). Sometimes lighting requirements may conflict with environmental considerations. However, it should be recognised that roundabouts are generally safer than other forms of at-grade junctions and the decision to use a roundabout should not be abandoned solely because of lighting problems. In sensitive locations it may be possible to adopt alternative lighting methods and other measures to make the roundabout more visible. When an existing roundabout junction is being modified, the lighting layout should be checked for suitability with the new road arrangement and any alteration carried out prior to, or at the same time as the roadworks. It is important that approaching drivers see and perceive that they are approaching a roundabout and are not misled by the projection of the lighting layout, particularly at times of poor visibility.

Mandatory Sections

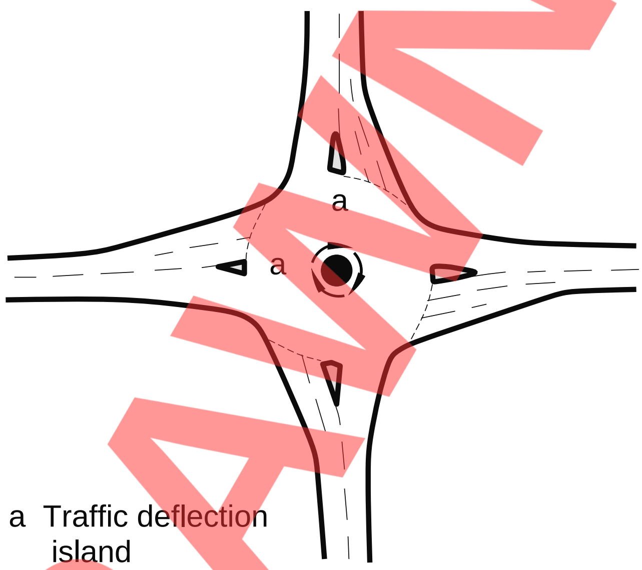
1.17 Sections of this document which form part of the standards the Overseeing Department expects in design are highlighted by being contained in boxes. These are the sections with which the designer must comply. The remainder of the document contains advice and enlargement which is commended to designers for their consideration.

2. TYPES OF ROUNDABOUT

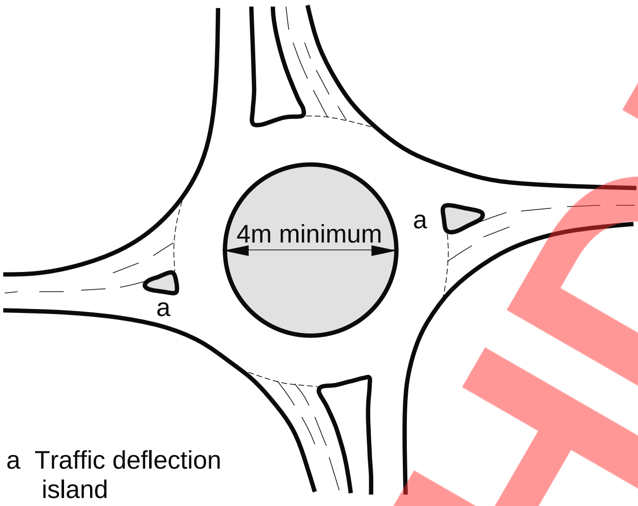
Definitions

2.1 The three main types of roundabout, Normal, Mini and Double, and other forms of roundabouts which are variants of these basic types, ie Ring Junctions, Grade Separated Roundabouts and Signalised Roundabouts, are defined as follows:-

a **Normal Roundabout:** a roundabout having a one-way circulatory carriageway around a kerbed central island 4m or more in diameter and usually with flared approaches to allow multiple vehicle entry. (Fig 2/1).

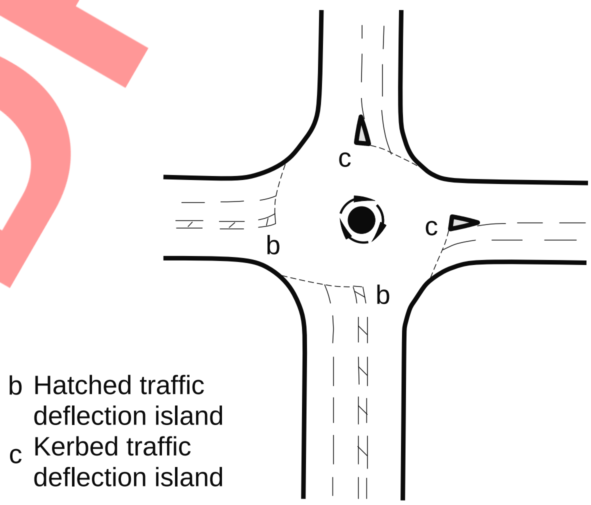


Mini Roundabouts : 4 - Arm Junction with flared Approaches
Figure 2/2a



Normal Roundabout
Figure 2/1

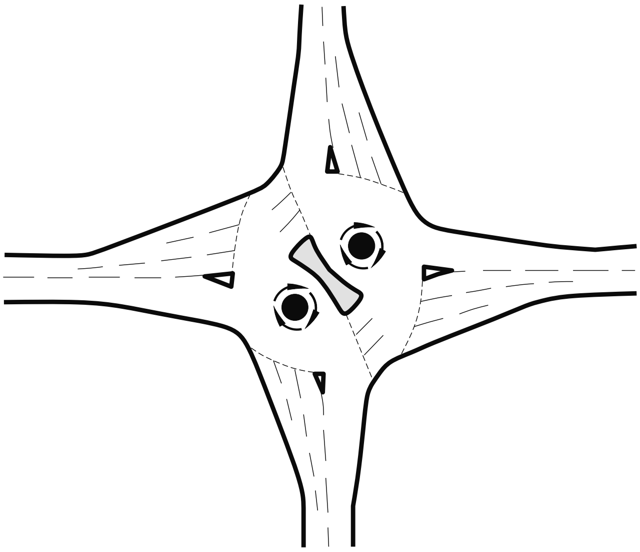
b **Mini Roundabout:** a roundabout having a one-way circulatory carriageway around a flush or slightly raised circular marking less than 4m in diameter and with or without flared approaches. (Figs 2/2a and 2/2b).



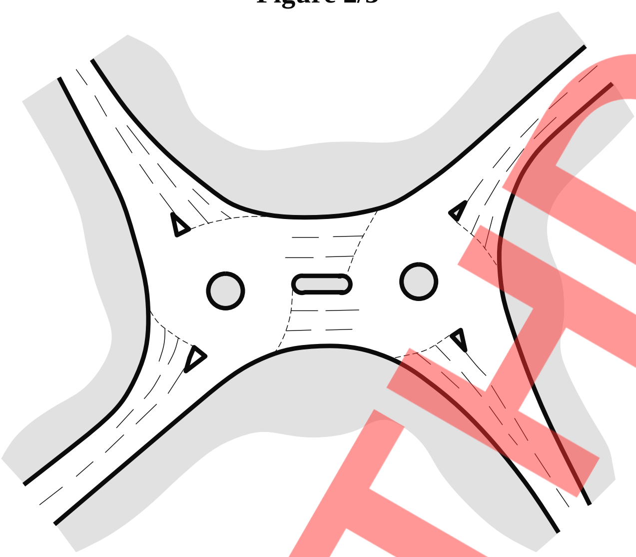
Mini Roundabout : 4 - Arm Junction without Flared Approaches

Figure 2/2b

c **Double Roundabout:** an individual junction with two normal or mini roundabouts either contiguous (Fig 2/3), or connected by a central link road or kerbed island (Fig 2/4).



Contigous Double Roundabout
Figure 2/3



Double Roundabout with Short Central Link road
Figure 2/4

d **Grade Separated Roundabout Junction.** A roundabout which has at least one entry road via an inter-connecting slip road from a road at a different level, (eg underpasses, flyovers or multiple level intersections), (Fig 2/5 and 2/6).

e **Ring Junction**. A junction arrangement where the usual clockwise one-way circulation of vehicles around a large island is replaced by two-way circulation with three arm mini roundabouts and/or traffic signals at the junction of each approach arm with the circulatory carriageway.

f **Signalised Roundabout**. A roundabout which has traffic signals installed on one or more of the approach arms.

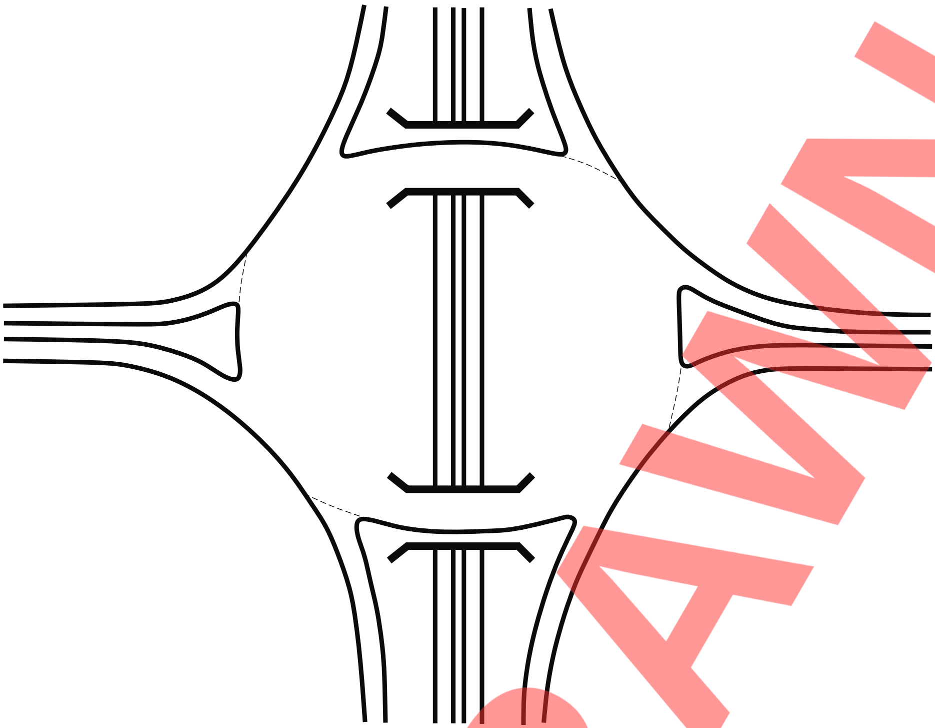
Normal Roundabouts

2.2 The number of entries recommended is either 3 or 4. Roundabouts perform particularly well with 3 arms, being more efficient than signals, provided the traffic demand is well balanced between the arms. If the number of entries is above 4, driver comprehension is affected and the roundabout becomes larger with the probability that higher circulatory speeds will be generated. Double roundabouts should be considered as a potential solution in these circumstances.

Mini Roundabouts

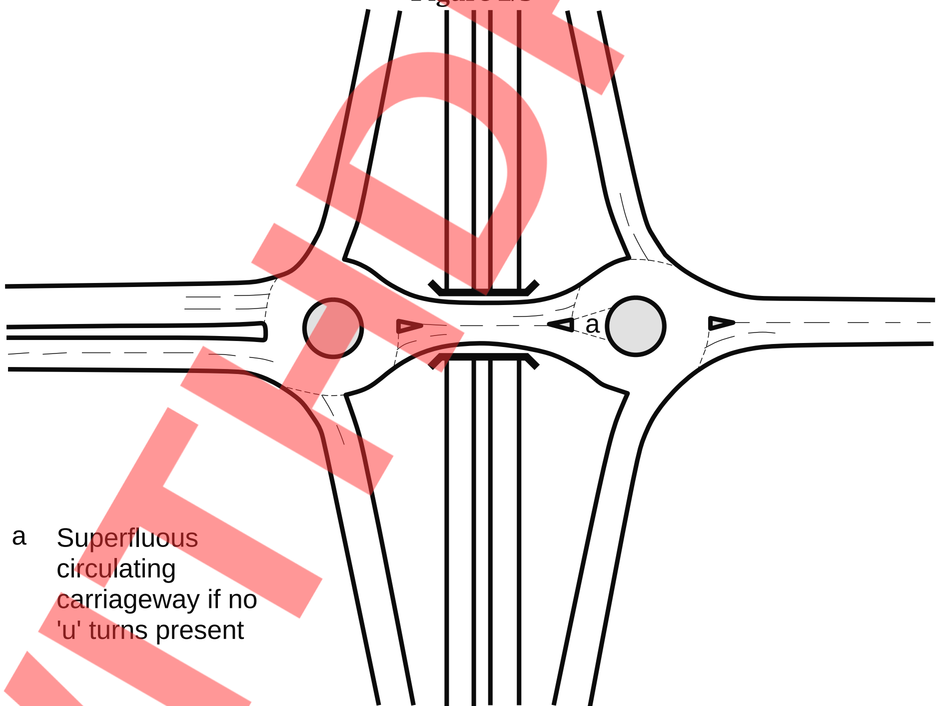
2.3 Mini-roundabouts can be extremely effective in improving existing urban junctions that experience safety and side road delay problems. Their layout should be designed so that drivers are made aware in good time that they are approaching a roundabout. They should only be used when all the approaches are subject to a 30 mph speed limit or less. Their use on roads with higher speed limits is not recommended.

2.4 Where physical deflection is not possible on approaches, road markings and small traffic deflection islands should be used to induce some vehicle deflection. These islands should be kept free of all furniture except the "Keep Left" bollards and other essential signs. If satisfactory deflection can not be achieved, the speed of approach traffic can be reduced by the use of traffic calming islands as carriageway width restrictions on the junction approach. These islands may also serve as pedestrian refuges. Sufficient width should be left for cyclists.



Two Bridge Roundabout at Grade Separated Interchange

Figure 2/5



Grade Separated Interchange with One Bridge and Two Roundabouts - 'Dumbell Interchange'

Figure 2/6

2.5 The circular marking (1 to 4 m diameter) (Fig 2/2) should be as large as possible in relation to the site and be domed up to a maximum height of 125mm at the centre for a 4 m diameter island. For smaller islands the height of the dome should be reduced pro-rata. This doming, in conjunction with the presence of some adverse crossfall, will help to make the roundabout more conspicuous to drivers. No bollards, signs, lighting columns or other street furniture should be placed on the dome.

2.6 The dome is usually constructed of bituminous material, concrete or block paving with a hard surround 6mm to 15mm proud of the surrounding road surface. Techniques whereby a precast dome is fixed with adhesives to an existing road surface have proved successful.

2.7 The dome should be completely white and reflectorised. A ring of omni-directional reflective road studs around the periphery of the dome have been found effective. Domes surfaced with materials such as natural stone sets which do not contrast with the surrounding road surface are not sufficiently conspicuous at times of bad visibility.

2.8 At junctions where space is very restricted, the repeated overrunning of the central marking by long vehicles will be unavoidable. In these cases the central markings may be merely a flat circle marked on the road and its periphery may be delineated by reflective road studs, but in such cases there may be less observance of the painted island by light vehicles. There is some evidence to suggest that this increases the accident risk.

2.9 "U" turn manoeuvres at mini-roundabouts are often unexpected due to the compactness of the junction. Whilst they should not be prevented, care should be taken not to create "U" turns unnecessarily. The use of mini-roundabouts at the end of dual carriageways, or linear traffic management schemes where right turns into or out of side roads are prohibited is not recommended. Most mini-roundabouts involve tight turning manoeuvres which produce severe heavy tyre scuffing actions. They should, therefore, be inspected regularly to ensure that road and dome markings are intact and readily visible.

2.10 Because of the short distance between entries, mini-roundabouts require entering drivers to observe closely other vehicles in the junction and on the approaches and react quickly when a gap occurs. In these circumstances pedal cyclists can be overlooked. However, the indications are that cyclists are no more vulnerable at mini-roundabouts than at four arm traffic signals. Therefore, provided that excessive approach speeds are discouraged or prevented, mini-roundabouts can be used where there are expected to be cyclists.

2.11 Although not based directly on mini roundabout data, ARCADY/3 is as good as any available method for determining mini roundabout capacities. However, results should be viewed with some caution. ARCADY/3 cannot at present be used for safety and accident assessments for mini roundabouts.

Double Roundabouts

2.12 Cases where double roundabouts can be particularly useful include:-

a. the improvement of an existing staggered junction where it avoids the need to realign one of the approach roads, and achieves a considerable construction cost saving;

b. at unusual or asymmetrical junctions, such as a `scissors' junction, (see Fig 2/4) where the installation of a single island roundabout would require extensive realignment of the approaches or excessive land take;

c. the joining of two parallel routes separated by a feature such as river, railway line or motorway;

d. at existing crossroads where it separates opposing right turning movements allowing them to pass nearside to nearside as shown in Fig 2/3;

e. at overloaded single roundabouts where, by reducing the circulating flow past critical entries, it increases capacity;

f. at junctions with more than four entries, a double roundabout achieves better capacity with acceptable safety characteristics in conjunction with a more efficient use of space, whereas large roundabouts can generate high circulatory speeds with consequent loss of capacity and safety.

2.13 Where the double roundabout is comprised of mini-roundabouts they should only be used when all the approaches are subject to a 30 mph speed limit.

Grade Separated Roundabout Junctions

2.14 The most common forms of roundabout used at grade separated junctions are the two bridge type (Fig 2/5) and the dumbbell type (Fig 2/6).

2.15 **Two Bridge Roundabout**. There have been problems in the past with some layouts of this type due to their large size, which permit high circulatory speeds. This can cause problems for drivers trying to enter the system. Thus when adopting this type of layout every effort should be made to achieve compact designs. If this can not be achieved, then on large gyratories reducing the width of longer sections can help to control speeds, and can also provide the option for more suitable entries using a form of "lane gain".

2.16 **Dumbbell Roundabout**. This type of layout forms a useful intermediate junction between the single diamond interchange and the two bridge roundabout. It has the advantage of compactness and low construction costs. The standards for deflection and visibility should apply to each of the two roundabouts though in the case of the connecting link the design speed, and hence forward visibility, is likely to be less than for the external arms.

2.17 Capacity assessment should not only consider the whole junction, but connecting link approaches should be considered separately to ensure that interactive queuing between the roundabouts does not occur. In situations where there are no "U" turn movements a full roundabout may not be necessary. However, an unbalanced flow situation can arise, or higher speeds in the dominant flow, and care should be taken to ensure that this does not result in excessive queues on exit slip roads.

Ring Junctions

2.18 Some unusual types of roundabouts, for example ring junctions, have been found to work well in solving problems at existing junctions. Ring junctions allow two way traffic on the circulatory system and require drivers on the circulatory system to give way. The connection with the entry arms is usually made with a small or mini roundabout, or it may be signalled.

2.19 The conversion to ring junctions is an effective solution for very large roundabouts which exhibit entry problems. This type of layout can eliminate congestion problems without reducing safety.

2.20 A ring junction will not operate successfully unless the signing is clear, concise and unambiguous, and careful consideration should be given to this aspect at the design stage.

Signalised Roundabout

2.21 Where a roundabout does not function well because of growth in traffic flow, or is likely to experience an overloading or an unbalanced flow at one or more entries, or high circulatory speeds, thereby defeating the self-regulating nature of the junction, it may be possible to alleviate the problem by installing traffic signals, (either `continuous' or `part-time' operation) at some or all of the entry points (See DMRB 8.1)

3. THE SITING OF ROUNDABOUTS

3.1 The decision to provide a roundabout rather than some other form of junction should be based on operational, economic and environmental considerations. See TA 23 (DMRB 6.2) and TA 30 (DMRB 5.1). Factors to be taken into account at the design stage include, for example, the need to induce "through traffic" to reduce speed at certain places for reasons such as:-

a. A significant change in road standard, say from dual to single carriageways or from grade separated junction roads to at-grade junction roads, although complete reliance should not be placed on the roundabout alone to act as an indicator to drivers;

b. To emphasise the transition from a rural to an urban or suburban environment;

c. Also a roundabout junction can be used in lieu of very sharp changes in route direction which could not be achieved by curves, even of substandard radii.

3.2 On single carriageways where overtaking opportunity is limited, the siting of roundabouts can optimise the length of straight overtaking sections on either side of them. (See TD 9 DMRB 6.1.1). They can also be used to provide an overtaking opportunity on the exit side by the provision of a short length of two lanes in the exit direction, either treated as a dual carriageway or separated by road markings. The length of such a section should be determined in the light of site conditions.

3.3 Roundabouts should be sited on level ground preferably, or in sags rather than at or near the crests of hills because it is difficult for drivers to appreciate the layout when approaching on an up gradient. However, there is no evidence that roundabouts on hill tops are intrinsically dangerous if correctly signed and where the visibility standards have been provided on the approach to the "Give Way" line. Roundabouts should not normally be sited immediately at the bottom of long descents where the down grade is significant for Large Goods Vehicles and loss of control could occur.

3.4 Roundabouts are applicable in urban areas but they are not generally compatible with Urban Traffic Control (UTC) systems. These systems move vehicles through their controlled areas in platoons by adjusting traffic signal times to suit the required progress. Roundabouts interfere with platoon movement to the extent that subsequent inflows to downstreams traffic signals cannot be reliably predicted, and thus the sequence breaks down.

3.5 The majority of accidents at major/minor junctions and accesses are associated with right turns. The banning of such right turns can be accomplished by providing a roundabout at a more important junction nearby.

3.6 Where a proposed roundabout may have an operational effect on an adjacent junction, or vice versa, the interactive effects must be examined and where appropriate, traffic management measures such as prohibited turns (physical or by traffic regulation order) or one way traffic orders may need to be considered.

3.7 Roundabouts are not normally recommended at rural dual three lane all-purpose road at-grade junctions. Under these conditions it is difficult to achieve adequate deflection.

3.8 Roundabout design shall be related to the Design Speed of the approach roads irrespective of speed limits (but see para 2.3). For completely new road schemes this shall be estimated in accordance with the method described in TD 9 (DMRB 6.1.1). For new or improved layout designs on the existing network, the design shall be based on the 85 percentile "wet weather" speed on each approach road. This shall be measured and adjusted in accordance with TA 22 (DMRB 5.1), at a point sufficiently distant from an existing junction as to be unaffected by its presence and the speed shall be rounded up to the nearest Design Speed above. Corresponding positions shall be estimated for new roundabouts on existing roads.

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3.9 Small roundabouts sometimes use less land than alternative single lane dualling, and can thus be attractive in sensitive areas.

4. SAFETY

4.1 In 1990 there were about 258,000 personal injury accidents in Great Britain. Of these, about 14,100 (5.5%) occurred at roundabouts. The proportion of accidents at roundabouts which were fatal was 0.43%, whereas 1.3% of all other junction accidents and 2.8% of link accidents were fatal; this indicates how effective roundabouts are in reducing road accident severity at junctions. From Road Accidents in Great Britain 1990, the average accident cost at a roundabout can be calculated as about 50% less than that at all other junctions and about 70% less than that on links.

4.2 A study by Hall and Surl showed that on well trafficked dual carriageways, for similar flows on both roads a roundabout will generally have fewer accidents than a signalised junction.

4.3 Nevertheless, notwithstanding their good record, great care must be taken in layout design to secure the essential safety aspects. The most common problem affecting safety is excessive speed, both at entry or within the roundabout. The most significant factors contributing to high entry and circulating speeds are:-

a. Inadequate entry deflection.

b. A very acute entry angle which encourages fast merging manoeuvres with circulating traffic.

c. Poor visibility to the "Give Way" line.

d. Poorly designed or positioned warning and advance direction signing.

e. "Reduce Speed Now" signs, where provided, being incorrectly sited.

f. More than four entries leading to a large configuration.

4.4 Additionally safety aspects to be considered in designing a layout include:-

a. Angle between arms: The accident potential of an entry depends on both the angle clockwise between its approach arm and the next approach arm, and the traffic flows. A high flow entry should have a large angle to the next entry, and a low flow entry a smaller angle in order to minimise accidents. (Ref TRL Report LR 1120 Accidents at 4-Arm Roundabouts).

b. Gradient: Whilst it is normal to flatten approach gradients to about 2% or less at entry, research at a limited number of sites has shown that this has only a small beneficial effect on accident potential.

c. Visibility to the right at entry: This has comparatively little influence upon accident risk; there is nothing to be gained by increasing visibility above the recommended level.

4.5 Measures that have been found to be useful in reducing accidents at existing roundabouts having poorer safety records include:-

a. The repositioning or reinforcement of warning signs, the provision of map type advance direction signs, making the "Give Way" line more conspicuous, moving the central island chevron sign further to the left to emphasise the angle of turn, placing another chevron sign above the normal position, and placing chevron signs in the central reserve in line with the offside lane approach on dual carriageways. Chevron boards can impinge on circulatory visibility but the effects can be minimised by positioning the boards (and associated turn left sign) 2m back from the central island kerbline. When approach speeds are low (usually in urban areas), a ring of contrasting paving can be laid in a chevron pattern inside the central island perimeter at a gentle slope (paragraph 6.6 and Fig 6/1) as an alternative to chevron boards; where approach speeds are high it can provide a useful supplement.

b. The provision of "Yellow Bar Markings" on fast dual carriageway approaches, (TD 6 DMRB 8.2). TRL Report LR 1010 demonstrates that a 57% reduction in accidents can be achieved with yellow bar markings.

c. The provision of appropriate levels of skidding resistance on the approaches to roundabouts and on the circulatory carriageways. It should be noted that at the speed of traffic on a circulatory carriageway, skidding resistance is derived from the surface texture of the aggregates which form the surface of the road - (the micro-texture). It is, therefore, very important to ensure that the aggregates used have skid resisting properties appropriate to the circumstances. It should be noted that deep surface texture - (the macro-texture) necessary for good skid resistance on high speed routes is not required for circulatory carriageways. Deep surface texture is required however, on the approaches to roundabouts if the 85%ile speed of traffic is greater than

55 mph (90 kph). Further information is given in Standard HD 21 (DMRB 7.2.1) and Advice Note HA 45 (DMRB 7.2.2).

d. The avoidance of abrupt and excessive superelevation in the entry region.

e. The reduction of excessive entry width by hatching or physical means.

f. The provision of "Reduce Speed Now" signs and/or "Count-down" markers.

4.6 Care should be taken with the choice of kerb type for roundabout design. A safety problem can arise where certain specialist high profile kerbs are used around a central island as they can be a danger to vehicles over running the entry. Observations have shown that these kerbs can result in loss of control or overturning of vehicles unless the approach angle is small and actual vehicle speeds are low. Where high profile kerbs are to be used on approaches, the kerbs can be hazardous for pedestrians and consideration should be given to the provision of pedestrian guardrails.

4.7 High circulatory speeds cause associated entry problems and normally occur at large roundabouts with excessively long and/or wide circulatory carriageways. But they can also be caused at smaller roundabouts by inadequate deflection at previous entries. The solution to high circulatory speeds usually has to be fairly drastic, involving the signalisation of problem entry arms at peak hours. In extreme cases the roundabout may have to be converted to a ring junction in which the circulatory carriageway is made 2-way and the entries/exits are controlled by individual mini or normal roundabouts, or traffic signals.

4.8 If entry problems are caused by poor visibility to the right, good results can be achieved by moving the "Give Way" line forward in conjunction with curtailing the adjacent circulatory carriageway by hatching or extension of the traffic deflection island.

Two Wheeled Vehicles

4.9 Though roundabouts have an impressive overall safety record for most vehicle types this does not apply equally to two wheeled vehicles. Research has shown that at four-arm roundabouts on Class A roads (TRL Report LR 1120), injury accidents involving two-wheeled vehicles constitute about half of all those reported. The proportion of accidents involving pedal cyclists is about 15%, although they typically constitute less than 2% of the traffic flow. The accident involvement rates for two-wheeled vehicles, expressed in terms of accidents per road user movement, are 10-15 times those of cars; with pedal cyclists generally having slightly higher accident rates than two-wheeled motor vehicle riders.

4.10 The study at four-arm roundabouts, TRL Report LR 1120, has shown for example that, in 30 and 40 mph speed limit areas, there are differences in pedal cycle accident involvement rates for different categories of roundabouts. Designers should be aware of the following:-

a. Normal roundabouts with small central islands and flared entries have accident rates which are about twice those of normal roundabouts with large central islands and unflared entries. This relationship appears to apply consistently for all types of vehicular road users. As previously stated, analysis of accident data suggests that when all types of accident are considered, entry deflection is the most important factor. (See paras 7.25 to 7.36);

b. 70 per cent of pedal cycle accidents at smaller normal roundabouts are of the `entry/circulating' type, for example, motor vehicle entering roundabout collides with pedal cycle crossing entry;

c. At dual carriageway roundabouts the accident involvement rate for cyclists is about two to three times greater than that at dual carriageway traffic signals but for cars, the opposite is true.

4.11 Data for pedal cycle accident involvement rates in 50 to 70 mph speed limits were less reliable, due to low pedal cycle flows and few pedal cycle accidents, and did not show any significant differences between types of roundabout. The rates observed were similar to those for smaller normal roundabouts in 30 and 40 mph speed limits.

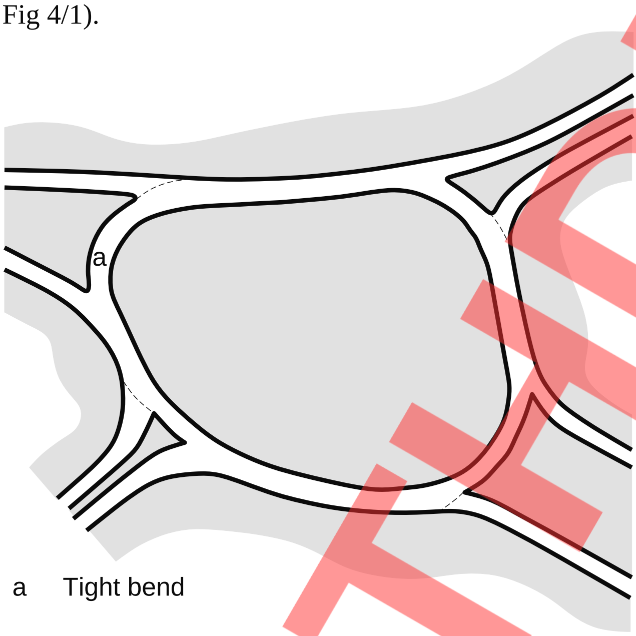
4.12 Comparable data for pedal cycle accidents at mini roundabouts, three-arm roundabouts and single carriageway traffic signals are reported in TRL Report CR 161.

Large Goods Vehicles

4.13 The problem of large goods vehicles overturning or shedding their loads at roundabouts has no obvious solution in relation to layout geometry. Whilst there are only about 60 personal injury accidents a year in this category, there are considerably more damage-only accidents. Load shedding often involves great congestion, and delay, and is expensive to clear, especially if occurring at major junctions. Experience suggests that roundabouts where these problems persist usually exhibit one or more of the following features:-

a. Inadequate entry deflection leading to high entry speeds.

b. Long straight sections of circulatory carriageway leading into deceptively tight bends. (See Fig 4/1).



a Tight bend

Example of unsatisfactory Tight Bend on Large Roundabout

Figure 4/1

c. Sharp turns into exits.

d. Excessive crossfall changes on the circulatory carriageway.

e. Excessive adverse crossfall on a nearside lane of the circulatory carriageway.

4.14 An incipient problem for some vehicles may be present even if high speeds are not occurring. Research has shown that an articulated large goods vehicle with a centre of gravity height of 2.5m above the ground can overturn on a 20m radius bend at speeds as low as 15 mph (24 kph). This is reported in TRL Report LR 788. Layouts designed in accordance with the recommendations in this document should mitigate the above problems, although during construction, particular attention should be paid to ensure that pavement surface tolerances are complied with and that abrupt changes in crossfall are avoided. Normally there are advantages in making the exit radii greater than the entry radii.

Accident Prediction

4.15 A further aspect of Road Safety is the use of predictive accident models as in ARCADY/3. These models are very useful at the feasibility study stage in assisting with junction choice. It is not adequate to use capacity as the main (or only) criterion for junction choice. Once a junction type has been chosen the predictive accident model should then be part of the detail design process to ensure that the final design minimises accident potential. This approach can also help to balance accident costs (or savings) against delay. At present, however, the ARCADY/3 software cannot deal with safety and accident assessments at mini roundabouts.

4.16 The above items are not exhaustive. Further advice on the investigation of accidents and remedial measures is given in the Accident Investigation and Prevention Manual.

5. ROAD USERS' SPECIFIC REQUIREMENTS

Cyclists' Facilities

5.1 Roundabouts are a particular hazard for pedal cyclists as has been outlined in paras 4.9 to 4.11. The operational performance and safety factors have been monitored at a number of experimental schemes aimed at improving cyclist's safety at roundabouts. These have included the use of with flow cycle lanes around the circulatory carriageway, conversion of peripheral footways to joint cyclist/pedestrian facilities, shared use of pedestrian subways and signposting alternative cycle routes away from the roundabout.

5.2 Evaluation of these has concluded that once a cyclist has entered a roundabout it is difficult to reduce risk, and that the use of shared facilities have limited use depending on the volumes of pedestrians and cyclists. Nevertheless, bearing in mind the practicalities and economics, it is important to consider the provision of facilities which take cyclists out of the circulatory carriageway at roundabouts by application of the following:-

a. Shared use by pedestrians and cyclists of a peripheral cycle track/footway;

b. A signposted alternative cycle route away from the roundabout;

c. Full grade separation, eg by a combined pedestrian/ cyclist subways system;

Failing these, then greater emphasis should be placed by the designer on the safety aspects of the design of the roundabout layout, rather than high capacity, by careful attention to the entries and flares.

5.3 If the volume of cyclists is significant but not high enough economically to justify segregated facilities then consideration should be given to signalising the roundabout or to an alternative form of junction with traffic signals. Further details on assessment methods are available from the Traffic Advisory Unit.

5.4 Signallised cycle crossings may be appropriate where there are no pedestrian requirements but roundabout arms may intersect a cycle track.

5.5 Special consideration should be given to cyclists at segregated left turn lanes. In these cases it might be appropriate to adopt the principles contained in Traffic Advisory Unit Leaflet 1/88, Provision for Cyclists at Grade Separated Junctions. Otherwise, it might be necessary to end the segregated left turn lane at a "Give Way" line on the exit (para 7.64).

Equestrians' Facilities

5.6 Where there is expected to be regular use of the approaches by ridden horses, of the order of more than 20 passages a week, consideration should be given to the provision of crossing places where the roundabout arms have to be crossed. These should preferably be crossed at some distance from the actual roundabout to permit suitable visibility to the roundabout by the rider. The principles are set out in TA 57 (DMRB 6.3). Segregated routes at the roundabout are to be preferred. This may involve some strengthening of verges, but see TA 57. Ridden horses could share cycle tracks where these are distant from the circulating carriageway but should not be expected to use pedestrian facilities.

Pedestrians' Facilities

5.7 Separate pedestrian routes with crossings away from the flared entries to roundabouts are preferable. Here the carriageway widths are less and vehicular traffic movements are more straightforward. However, this is not always practical, in which case the following facilities should normally be considered:-

a. Unmarked crossing place (ie dropped kerbs), with a central refuge if possible.

b. Zebra crossing, with or without central refuge.

c. Some form of controlled crossing with or without a central refuge which includes for cyclists.

d. Subway or footbridge.

5.8 The type of facility selected will depend upon the volumes and movements expected of both pedestrians and traffic and should be designed in accordance with current recommendations and requirements (DMRB 2.2; 6.3; 8.5). The use of different types of facility at the same junction is not recommended as this could lead to confusion by pedestrians and drivers. Crossings should not be placed across multi-lane entries. They should be located away from the junction where the carriageway is relatively narrow.

5.9 If a crossing giving pedestrian priority is provided close to the entry/exit points of a roundabout there will be inevitable consequences for the operation of the roundabout and possibly for safety. Where a crossing must be provided within the junction layout, a zebra crossing is preferred; it avoids any ambiguity as to priority that the lights of the pelican can create for the driver approaching the roundabout "Give Way" line. If a signalised crossing is provided, it should preferably be of the divided crossing type to avoid excessive delays at the exit points, because the `blocking back' mechanism causes queues to extend onto the circulatory carriageway. For information on the effect of zebra crossings on junction flows, see TRL Report SR 724, the calculation methods of which are incorporated in ARCADY/3, and for more detailed advice on the location of pedestrian crossings, see DMRB 8.5.

5.10 In urban areas, where large numbers of pedestrians are present, guard rails or other means of deterring pedestrians from crossing should be used to prevent indiscriminate crossing of the carriageway. The design of guard railing should not obstruct drivers' visibility requirements. Guard rails, which are designed to maintain drivers' visibility to pedestrians through them, and vice-versa, are available, but should be checked in case blind spots do occur. TA 57 (DMRB 6.3) refers.

6. LANDSCAPING

6.1 The design of landscaping within the highway limits shall be carried out in consultation with appropriate specialists. The designer shall consider the maintenance implications and where the responsibility for maintenance is passed to a third party, maintenance standards must be agreed. If third parties wish to enhance the standard of planting or landscaping at roundabouts, for example: special floral displays, this shall only be with the agreement of the Overseeing Department, and shall not compromise visibility or safety. Further advice is given in the Good Roads Guide (DMRB Vol 10).

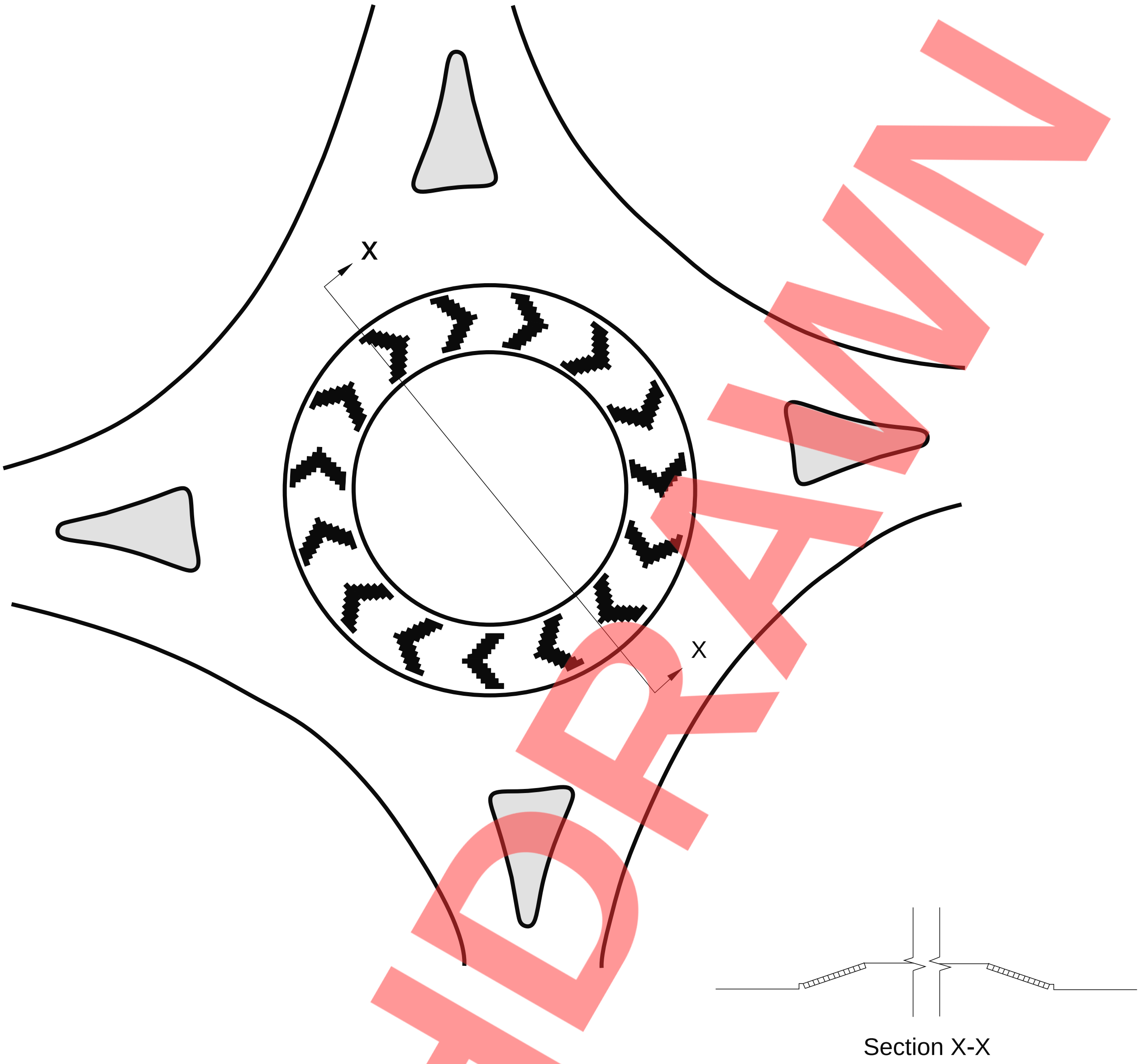
6.2 Apart from the amenity benefits, the landscape treatment of roundabouts can have practical advantages from a traffic engineering point of view. By earth modelling, perhaps in conjunction with planting, the presence of the roundabout can be made more obvious to approaching traffic. The screening of traffic on the opposite side of the roundabout to the point of entry can, without restricting necessary visibility, avoid distraction and confusion caused by traffic movements of no concern to a driver. Planting can provide a positive background to chevron signs and direction signs on the central island while visually uniting the various vertical features and reducing any appearance of clutter.

6.3 By careful planning, the areas required for visibility envelopes can be planted with species having a low mature height, with higher and denser species of bushes and coppiced trees, without thick trunks, towards the centre of the island. Specialised planting, which might be more appropriate in an urban area, generally requires greater maintenance effort if it is to be successful. Any planting must have bulk and substance in winter as well as during the summer months.

6.4 In rural areas planting should be restricted to indigenous species and be related to the surrounding landscape. In an open moorland, for example, any planting of other than local species would appear incongruous and landscape treatment would normally be restricted to ground modelling. Conversely in woodland areas roundabouts should be as densely planted as the demands of visibility permit with due allowance for the situation that will develop with matured growth.

6.5 Generally the planting of roundabout central island less than 10m in diameter is inappropriate as the need to provide driver visibility leaves only a small central area available. Such a restricted area of planting is out of scale with the roundabout as a whole, and becomes an incongruous "blob".

6.6 Recent experiments with a ring of black and white paving laid in a chevron pattern inside the central island perimeter at a gentle slope have proved successful in improving the conspicuity of central islands and they can be effective from a safety point of view (Fig 6/1). The chevron markings are a road sign currently available by special authorisation, although their inclusion among the Traffic Signs Regulations is being explored.



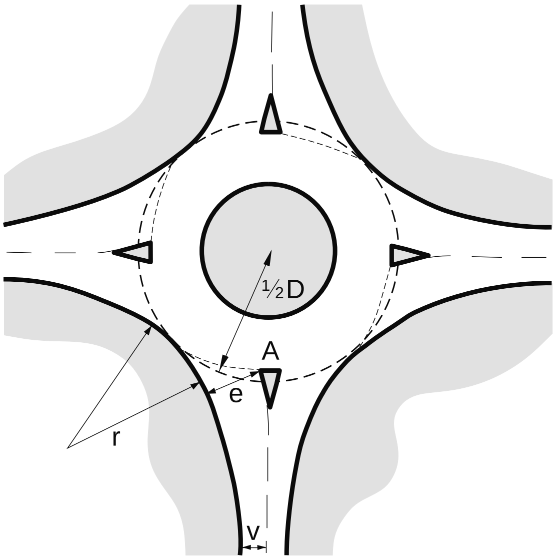
Contrasting Paving Chevron Markings for Normal Roundabouts

Figure 6/1

7. GEOMETRIC DESIGN FEATURES

Definitions

7.1 **Entry Width:** e, is measured from the point A along the normal to the nearside kerb, see Fig 7/1.



A Point of maximum entry deflection at right hand end of give-way line

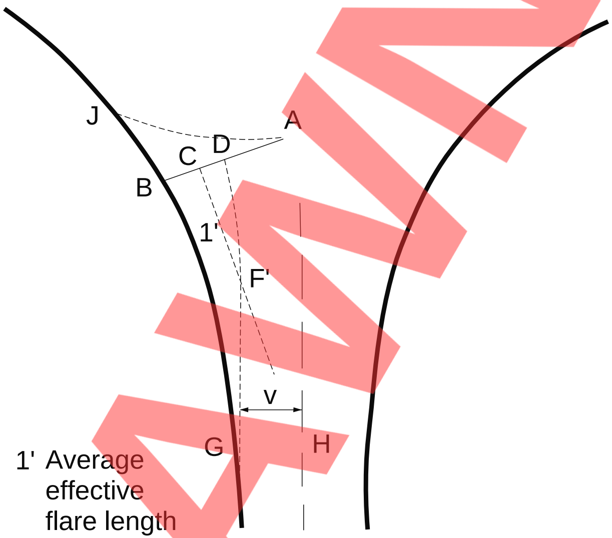
e Entry width
v Approach half width
r Entry Radius
D Inscribed circle Diameter

Geometric Design Features

Figure 7/1

7.2 **The Approach Half Width:** v, is measured at a point in the approach upstream from any entry flare, from the median line (or offside edge of carriageway on dual carriageways) to the nearside kerb, along a normal, see Fig 7/1.

7.3 **The Average Effective Flare Length:** l′, is found as shown in Fig 7/2. The line GF'D is the projection of the nearside kerb from the approach towards the "give way" line, parallel to the median HA and at a distance of v from it. BA is the line along which e is measured (and is therefore normal to GBJ), and thus D is at a



Average Effective Flare Length

Figure 7/2

distance of [e-v] from B. The line CF' is parallel to BG (the nearside kerb) and at a distance of [e-v]/2 from it. Usually the line CF' is therefore curved and its length is measured along the curve to obtain l′.

7.4 **The Sharpness of Flare:** S, is defined by the relationship:

$$S=1.6[e-v]/l'$$

and is a measure of the rate at which extra width is developed in the entry flare. Large values of S correspond to short severe flares and small values to long gradual flares.

7.5 **The Inscribed Circle Diameter:** D, is the diameter of the largest circle that can be inscribed within the junction outline, see Fig 7/1. In cases where the outline is asymmetric, the local value in the region of the entry is taken. The extreme case arises for a double roundabout at a "scissors" crossroads. Fig 7/3 illustrates the determination of D in such cases.

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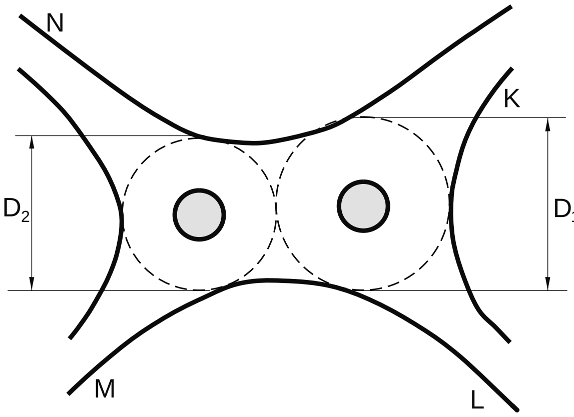
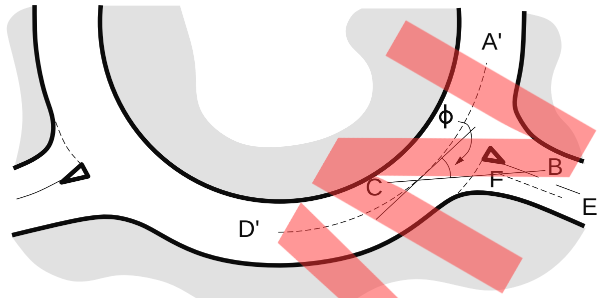


D_1 applies to entries K and L
D_2 applies to entries M and N

Geometric Design Features

Figure 7/3



ϕ Entry Angle

Entry Angle

Figure 7/5

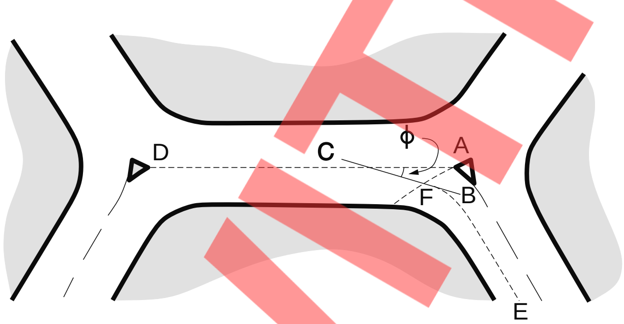
7.6 **The Entry Angle:** ϕ, serves as a geometric proxy for the conflict angle between entering and circulating streams. For roundabouts, having more than a distance of about 30m between the offsides of an entry and the next exit the construction is illustrated in Figs 7/4 and 7/5.

Fig 7/4 refers to roundabouts where the circulatory carriageway between an entry and the next exit is approximately straight. AD is parallel to the straight circulatory carriageway where A is as in Fig 7/1 and D is the point nearest to A on the median island (or marking) of the following entry.

Fig 7/5 shows the equivalent construction for roundabouts with curved circulatory carriageways (or those where the line AD in Fig 7/4 is clearly not parallel to the circulatory carriageway) A′D′ replaces AD as the line parallel to the circulatory carriageway.

In both cases the line BC is a tangent to the line EF, which is midway between the nearside kerbline and the median line or the edge of any median island on the offside, where this line intersects the "give way" line. ϕ is measured as the acute angle between the lines BC and AD in Fig 7/4, and as the acute angle between BC and the tangent to A′D′ at the point of intersection between BC and A′D′ shown in Fig 7/5.

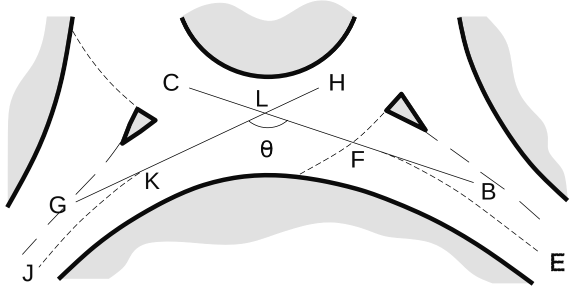
For all other roundabouts the construction is shown in Fig 7/6. The line BC is the same as in Figs 7/4 and 7/5. The line GH is the tangent to the line JK,



ϕ Entry Angle

Entry Angle

Figure 7/4



Entry angle ϕ defined as (90° - θ /2)

Entry Angle

Figure 7/6

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which is in the following exit midway between the nearside kerb and the median line or the edge of any median island on the offside, where this line intersects the outer edge of the circulatory carriageway. BC and GH intersect at L. ϕ is then defined by:

$$\phi = 90\text{-[angle GLB]}/2 \quad \text{ie HLB}/2$$

when the righthand side of the equation is positive.

When the righthand side of the equation is zero or negative, ϕ=0. Angle GLB is measured on the "outside" of the roundabout, that is, on the side facing away from the central island.

7.7 **The Entry Radius:** r is measured as the minimum radius of curvature of the nearside kerbline at entry, see Fig 7/1. For some designs the arc of minimum radius may extend into the following exit, but this is not important provided that a half or more of the arc length is within the entry region.

7.8 **Desirable Minimum Stopping Sight Distance:** as defined in TD 9 (DMRB 6.1.1)

7.9 **Entry Path Curvature:** This is a measure of the amount of entry deflection to the left imposed on vehicles at the entry to a roundabout, see paras 7.25 to 7.32.

7.10 **Traffic Deflection Island:** a raised area (usually kerbed) on the carriageway, which is located and shaped so as to direct and also separate traffic movements onto and from a roundabout.

7.11 **Ghost Islands used for Subsidiary Traffic Deflection:** a shaped area, flush with the road surface, delineated by road markings, and within the entry width of the approach to a roundabout, so located to deflect and direct traffic movements into the circulatory carriageway.

Entries

7.12 The design of roundabout entries is a complex procedure, there are several variables which need to be addressed to ensure a design which is safe and has adequate capacity.

The calculation of capacity is outlined in Annex 1.

7.13 The designer has flexibility in the application of the parameters to meet best the particular site requirements and constraints. The variables are:-

Entry Width
Flare Length
Entry Angle
Entry Radius
Approach carriageway half width

Entry Width

7.14 It is good practice to add at least one extra lane width to the lanes on the entry approach, but as a general rule not more than two lanes should be added and no entry should be more than four lanes wide. The relationship between entry width and capacity is quite significant. Entry width is the largest single factor, apart from approach carriageway half width, affecting capacity. There may be some cases, usually associated with low predicted flows, where increased entry width is not operationally necessary but in these circumstances it is still recommended that two entry lanes be provided; this will give added flexibility at abnormal flow periods in the future, a passing facility in the event of breakdown, and will ease the problem of space provision for long vehicles turning.

7.15 Lane widths at the "Give Way" line shall be not less than 3.0m.

Lane widths should be tapered back in the entry flare to a minimum width of 2m. It is generally better to use wide lane widths, because they are more suitable for large goods vehicles. For example, at a 10m wide entry, 3 x 3.33m lanes are better than 4 x 2.5m lanes.

7.16 The development of entry lanes should take account of the anticipated turning proportions and possible lane bias, since drivers often have a tendency to use the nearside lane. The use of lane bifurcation where a lane widens into two should maximise use of the entry width. The use of short offside lanes is not recommended.

7.17 The alignment of entry lanes is also critical. On rural roundabouts where design speeds are relatively high the kerbline of the deflection island (or central reserve in the case of a dual carriageway) should be on an arc which, when projected forward, meets the central island tangentially. In urban areas, where design speeds are lower, this is less important, but nevertheless should be achieved where possible. Care should be taken to ensure that the resultant entry angle is not too low nor that entry path curvature is not too great.

7.18 For capacity assessment, the entry width should be taken as the width which drivers are likely to use. Where the offside kerbline forms a vehicle path which is tangential to the central islands the entry width and effective entry width are the same.

7.19 It is usual to consider design flows 15 years after opening for highway schemes. This can result in roundabout entries with too many lanes for earlier year flows and lead to operational problems. A design year layout will determine overall geometry and land requirements for the roundabout but for the early years it may be necessary for the designer to consider an interim stage. This approach can result in reduced entry widths and entry lanes. Consideration can also be given to an interim reduction of the circulatory carriageway width either by an increase in diameter of the central island or by extending islands forward into the circulatory carriageway.

Flare Design At Entry

7.20 Flares on the approach to roundabouts shall be such that:-

a. the maximum entry width shall not exceed 10.5m for single and 15.0m for dual carriageway approach roads;

b. the average effective flare length shall not exceed 100m, but it should be noted that beyond 30 or 40m any expected extra capacity is derived from extrapolation beyond the bounds of experimental data and should therefore be treated with caution;

7.21 The capacity of an entry can be improved by increasing the average effective flare length, though this is of limited effect. A minimum length of about 5m is desirable in urban areas, whilst a length of 25m is considered adequate in rural areas. Flare lengths greater than 25m may assist in geometric layout but have little effect in increasing capacity. Flare lengths should not be greater than 100m as beyond this the design becomes one of link widening. Where the design speed is high, entry widening should be developed gradually avoiding any sharp angles. In urban areas the use of long flare lengths is often not possible due to land constraints and capacity may have to be achieved using wider entries and shorter flares. (As a rough guide, the total length of the entry widening (BG) should be about twice the average effective flare length l′ (Fig 7/2).

Entry Angle

7.22 The effect of entry angle on entry capacity is negative; as the angle increases capacity decreases slightly. However, care should be taken in the choice of entry angle since high and low angles may result in increased accident potential. The angle should, if possible, lie between 20 and 60 degrees, though some highway authorities prefer 30 to 40 degrees. Low entry angles force drivers into merging positions where they must either look over their shoulders to their right or attempt a true merge using their mirrors (with the attendant problems of disregarding the "Give Way" line and generation of high entry speeds). High entry angles produce excessive entry deflection and can lead to sharp braking at entries accompanied by "nose to tail" accidents, especially in rural areas. The best entry angle value is about 30 degrees. Figs 7/7 and 7/8 show two extreme cases.

Entry Radius

7.23 Entry capacity increases with entry radius up to about 20m, higher radii result in very little increase in capacity. The minimum entry radius should be 6m, a good practical design is about 20m. Where a roundabout is designed to cater for large goods vehicles in particular, the entry radius should not be less than 10m. Large entry radii will almost certainly result in inadequate entry deflection, for example it will not be possible to achieve the deflection standard if the entry radius is 100m or more.

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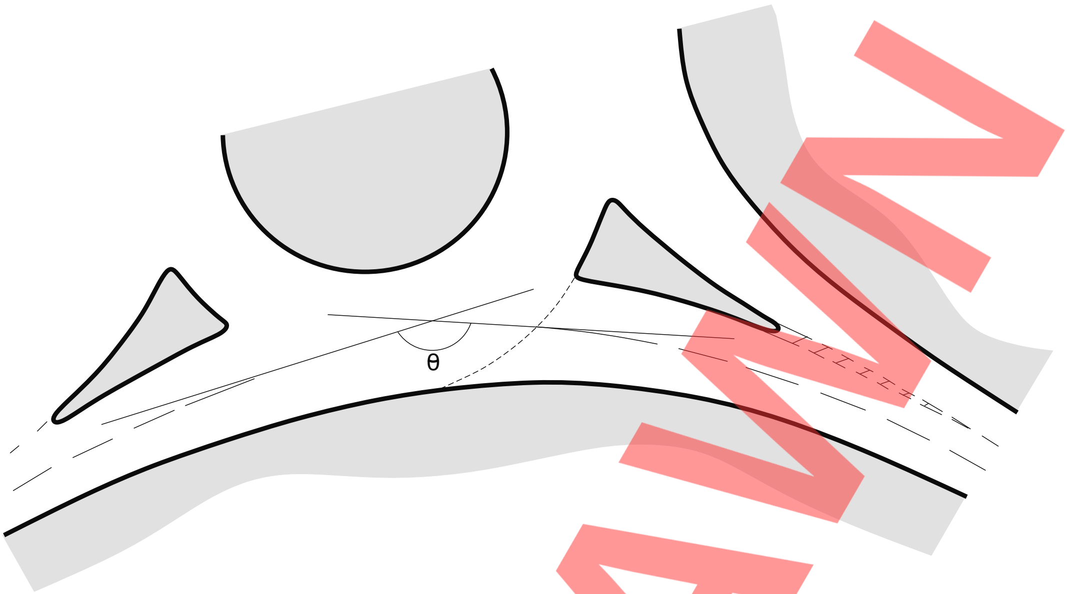
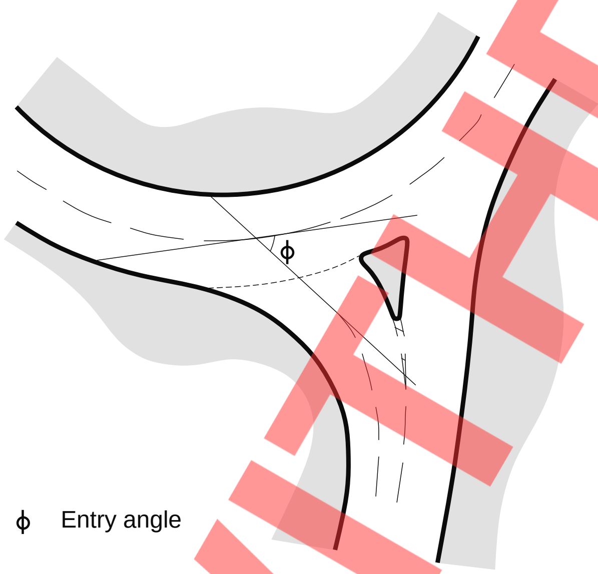


Entry angle is defined as (90° - θ /2)

Example of Too Low an Entry Angle and also Substandard Entry Deflection

Figure 7/7



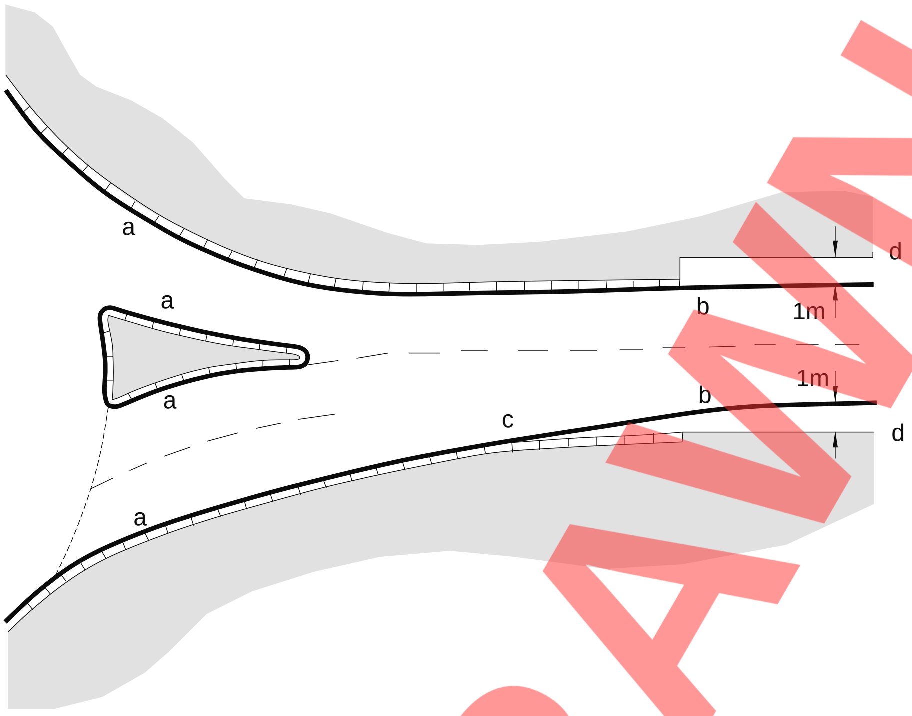
ϕ Entry angle

Example of Too High an Entry Angle and also Excessive Entry Deflection

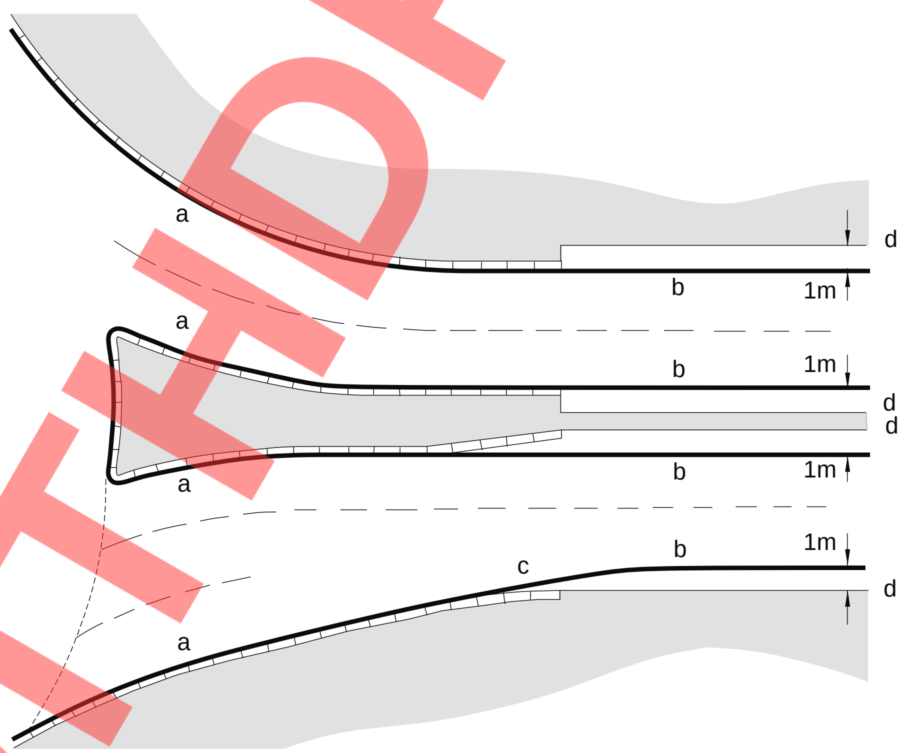
Figure 7/8

Entry Kerbing

7.24 As entries are almost always kerbed, hardstrips should be terminated when entry widening begins. The simplest procedure is to place the kerbs at the back of the hardstrip and then terminate the hardstrip edge line by profiling it back towards the kerbs in a short smooth curve or taper. (See Figs 7/9 and 7/10). This is not appropriate where there is regular use by cyclists who may wish to continue to the edge of the circulatory carriageway by using the hard strip. Where the roundabout is provided with cycle facilities (such as a peripheral cycle track), the hardstrip should link directly to these facilities.



Method of Terminating Edge Strips on Single Carriageway Approach to a Roundabout
Figure 7/9



a Kerbs
b Edge Lines
c Edge Line profiled back towards the kerb
d Edge of Carriageway

Method of Terminating Edge Strips on Dual Carriageway Approach to a Roundabout

Figure 7/10

Entry Deflection

7.25 Entry Path Curvature is one of the most important determinants of safety at roundabouts. It is a measure of the amount of entry deflection to the left imposed on vehicles at entry to the roundabout.

7.26 For design purposes only at both new and improved `normal' type roundabouts, the vehicle entry path shall be such that when scribed in accordance with the following construction, the tightest radius of the entry path curvature shall not exceed 100 metres. The method of constructing and measuring the entry path curvature is described below, and shown in Figs 7/11 to 7/15. Fig 7/13 shows an approach with negative curvature, Fig 7/14 shows an approach with positive approach curvature, and Fig 7/15 a roundabout at a "Y" junction.

7.27 Assume:-

a. The entering vehicle is 2m wide and will be taking the `straight ahead' movement at a 4 arm roundabout and across the head of the Tee at a 3 arm roundabout.

b. That there is no other traffic on the approach and on the circulatory carriageway.

c. That the driver will negotiate the site constraints with minimum deflections and that lane markings by the give way line will be ignored.

d. The initial approach position for entry path curvature measured from a point not less than 50m from the Give Way line, is within the range:-

1m from the nearside kerb
1m from the centre line of a single carriageway or
1m from the offside kerb of a dual carriageway

This will ensure that all approach alignments are examined and that no vehicle path can exceed the recommended maximum radius of curvature.

e. That the vehicle proceeds towards the "Give Way" line. Then either:-

it proceeds towards the central island of the roundabout passing through a point not less than 1m from the nearside channel or kerb, the position of which relative to the starting point (d above) depends on the amount of approach flare to the left (Fig 7/11 and Fig 7/13);
or where a subsidiary traffic deflection ghost island exists, it is assumed to pass whichever side of the island involves the least deflection (Fig 7/12).

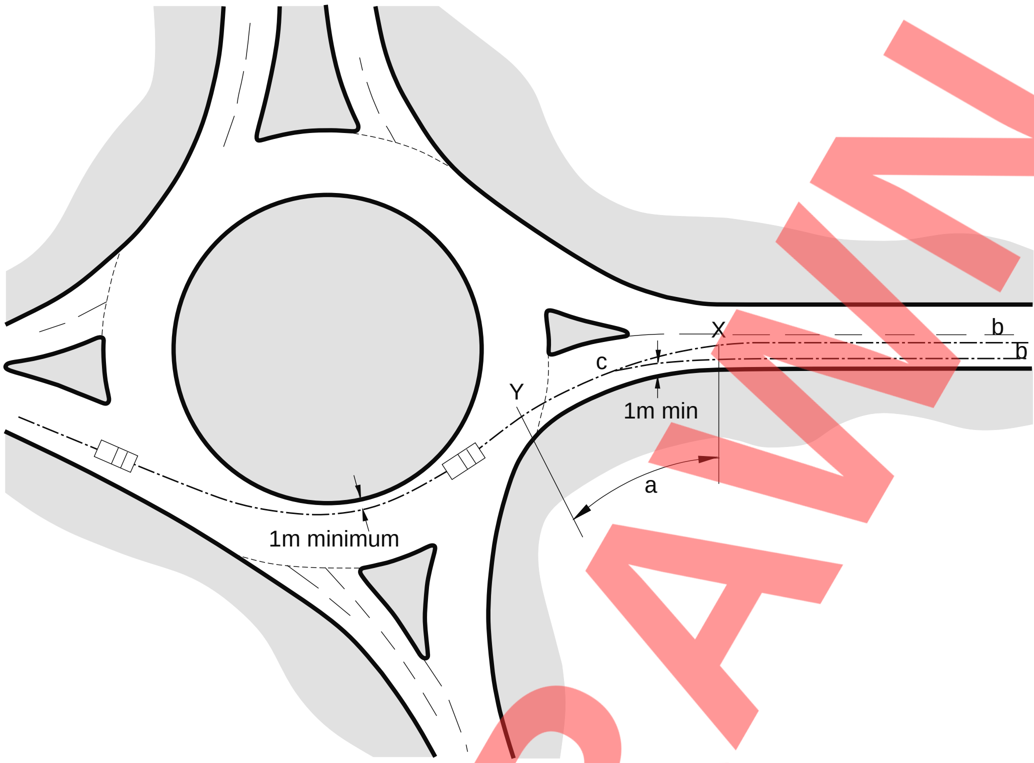
f. The vehicle is then assumed to continue on a smooth path with its centre-line never passing closer than 1m from the central island (it may be more in some configurations).

7.28 Draw, to a scale not less than 1/500 using a flexible curve or equivalent, the centre line of the most realistic path that a vehicle would take in its complete passage through the junction on a smooth alignment without sharp transitions. More than one independent assessment of the vehicle paths shall be carried out.

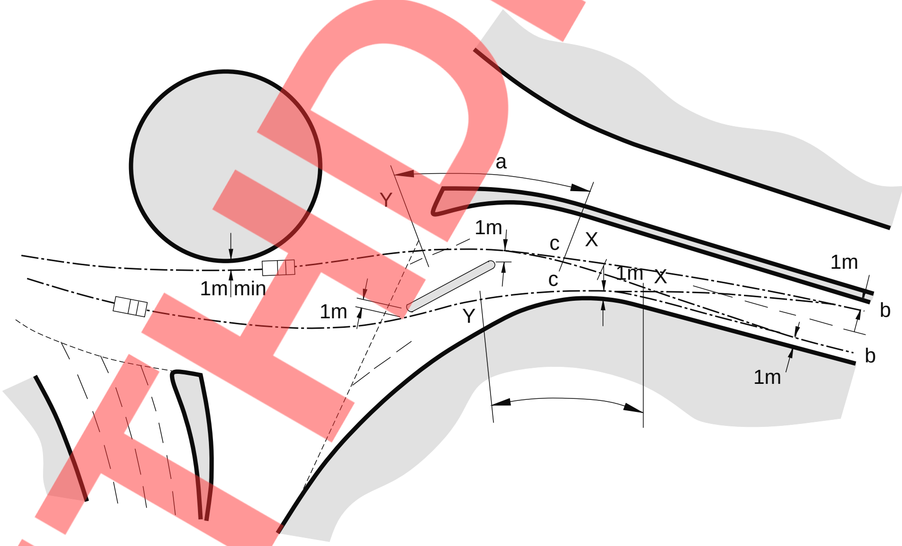
7.29 This tightest radius shall be measured by means of suitable templates. See para 7.32.

7.30 The exact path drawn will be a matter of personal judgement and the results should be examined for compliance and consistency with the appropriate paragraphs in this section.

7.31 One convenient method of construction of the required path is to imagine the advance of all the channel or kerb lines and centre line in the case of single carriageways (together with central islands and deflection islands) into the carriageway by 1m. The vehicle path will be the line of least resistance, whose centre line will normally, but not always, be tangential to these construction lines; in the entry, at the central island and in the exit. Any reverse of curvature in the vehicle path around the central island must be drawn so that there is no sharp deviation between that curve and the entry curve. Particular care in checking entry path curvature is required when considering small central island designs.



Determination of Entry Path Curvature
Figure 7/11



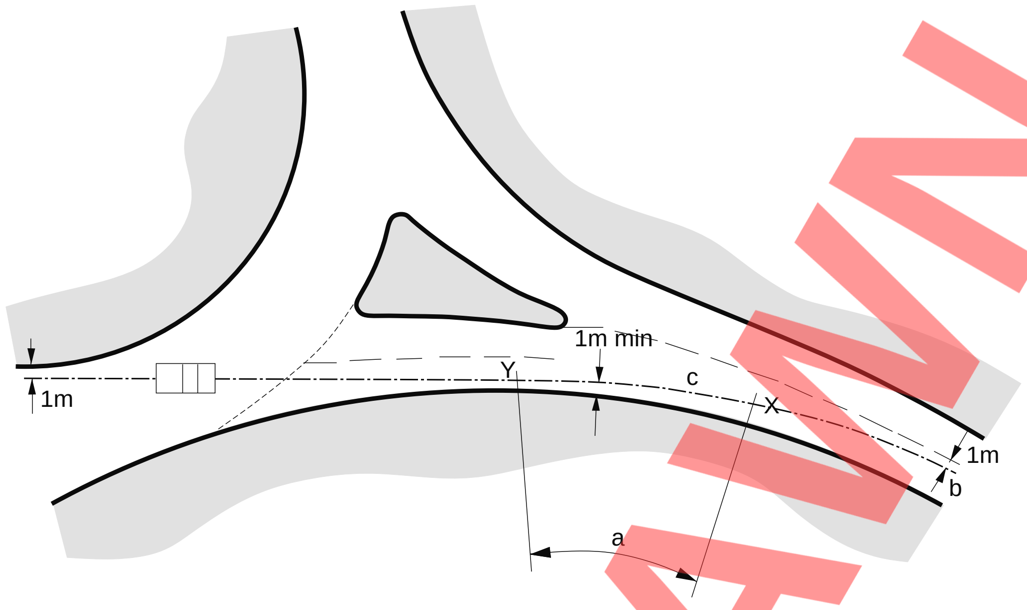
Determination of Entry Path Curvature
(when subsidiary traffic deflection islands exist)

Figure 7/12

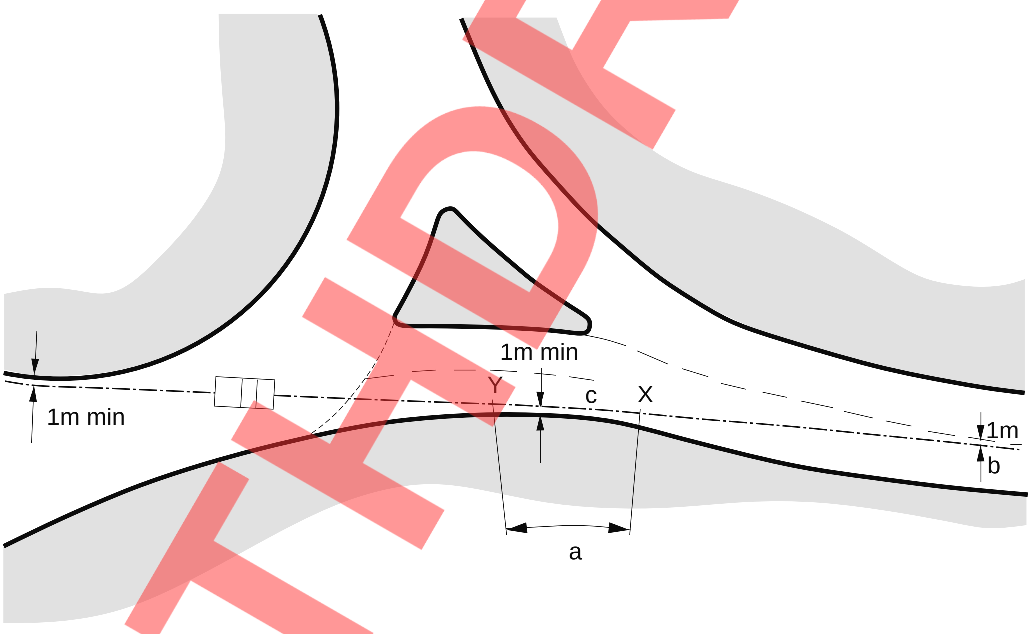
a The radius should be measured over a distance of 20-25m; it is the minimum which occurs along the approach entry path in the vicinity of the Give Way line but not more than 50m in advance of it.

b Commencement point either 1m from nearside kerb or 1m from offside kerb for D2L; 1m from nearside kerb or 1m from centreline S2L, at a point not less than 50m from the Give Way line.

c —·—·— Vehicle entry path curvature



Determination of Entry Path Curvature
(on a curved approach arm with negative approach curvature)
Figure 7/13

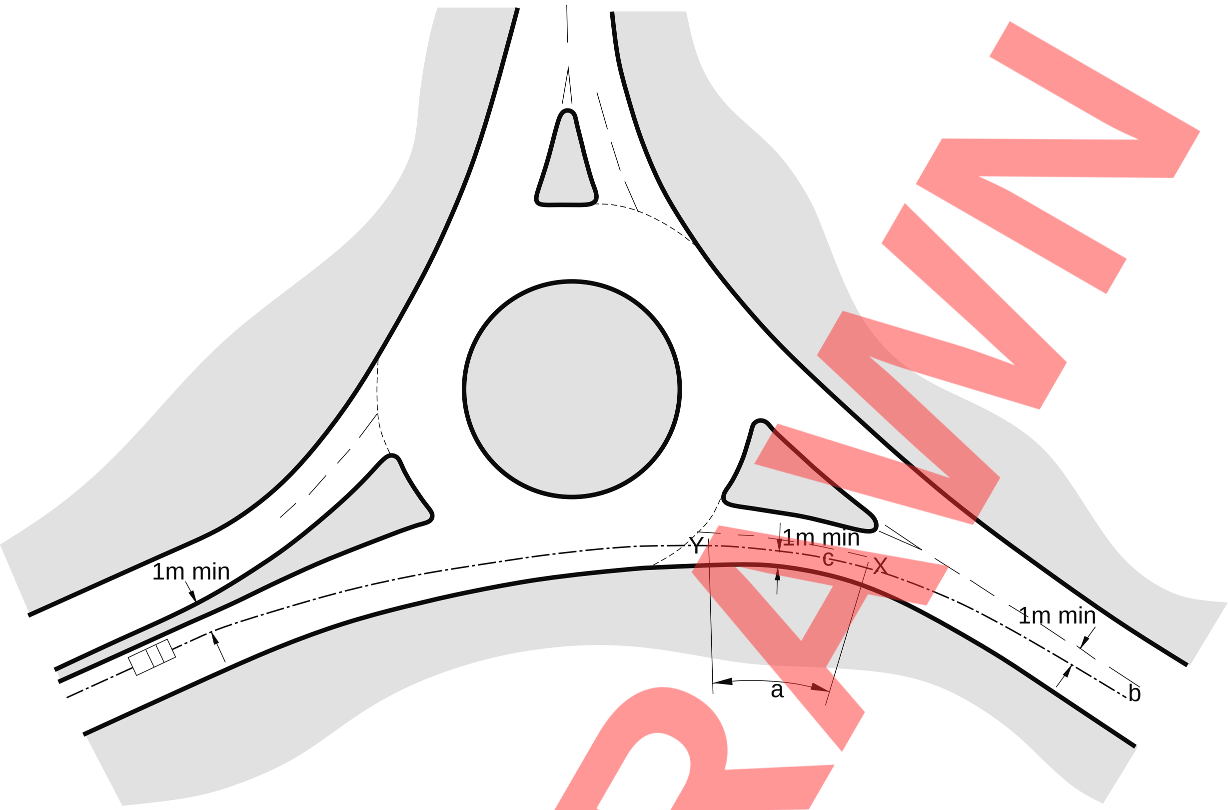


Determination of Entry Path Curvature
(on a curved approach arm with positive approach curvature)
Figure 7/14

a The radius should be measured over a distance of 20-25m; it is the minimum which occurs 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 1m from the offside kerb for D2L or 1m from centreline S2L, not less than 50m from the Give Way line.

c —·—·— Vehicle entry path curvature.



a The radius should be measured over a distance of 20-25m; it is the minimum which occurs 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 1m from offside kerb for D2 or 1m from centreline for S2L; not less than 50m from the Give Way line.

c —·—·—·— Vehicle entry path curvature

Determination of Entry Path Curvature for a Roundabout at a 'Y' Junction

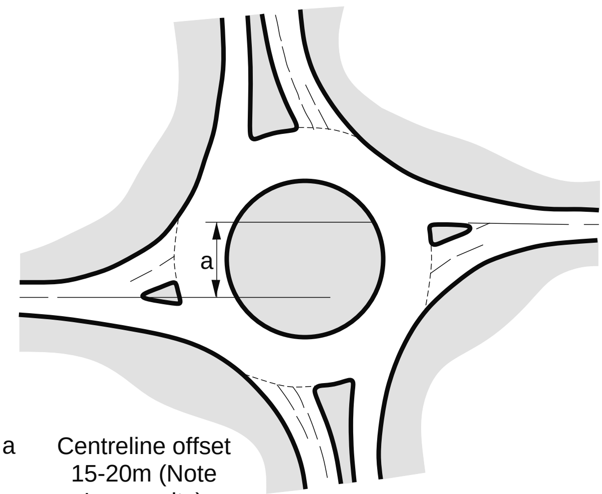
Figure 7/15

To Measure the Entry Path Curvature

7.32 The entry path curvature is measured on the curved length of path in the vicinity of the "Give Way" line (but not more than 50m in advance of it) between points X and Y (See Figs 7/11 to 7/15) about 20m to 25m but not less than 20m in length, over which the tightest radius occurs.

Achieving Entry Deflection

7.33 A good method for creating entry deflection on new schemes where there are no other constraints is to stagger the arms, as shown in Fig 7/16. This will help with the overall design, reduce the size of roundabouts, minimise land acquisition and assist with the construction of "easy" exits.



a Centreline offset 15-20m (Note 'easy exits)

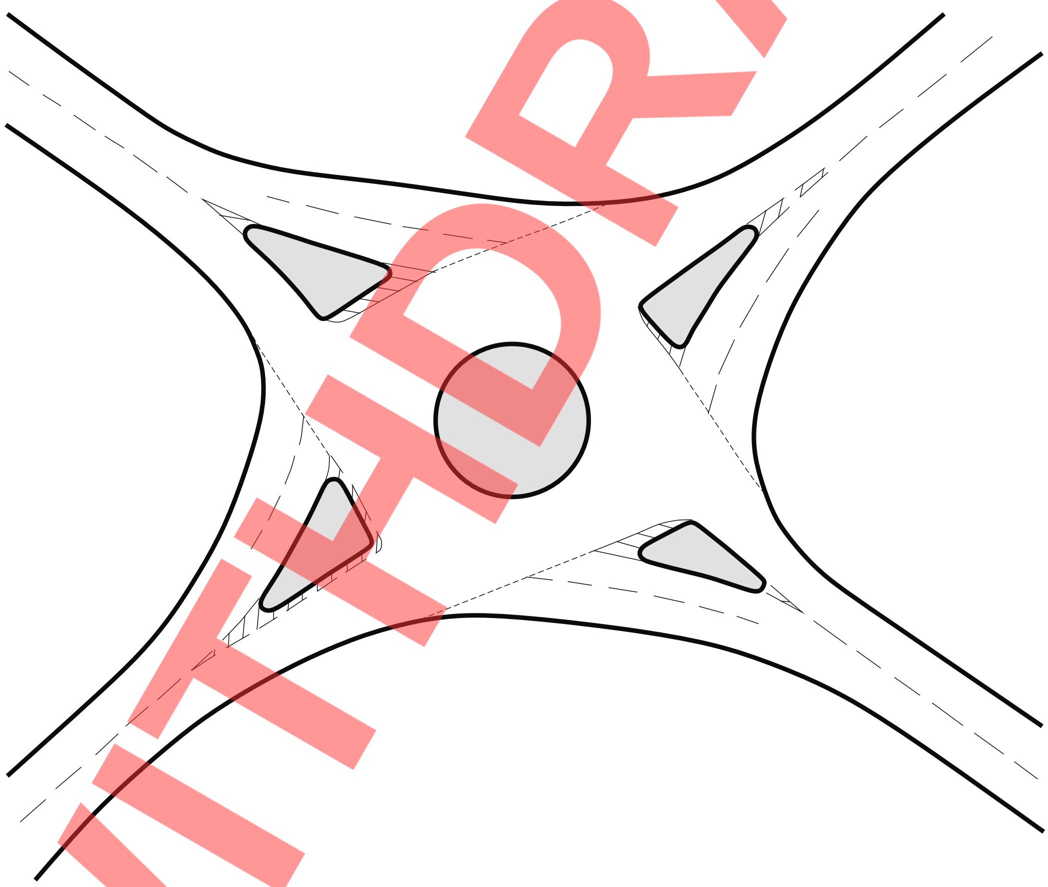
Entry Deflection by Staggering Approach Roads

Figure 7/16

7.34 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 but there are cases when horizontal radii below the minimum for the general design speed of the approach link may be used, provided always that they are proceeded by the "Roundabout Ahead" warning sign as defined in the Traffic Signs Regulations and General Directions. However, tight radii will require large amounts of verge widening to provide adequate forward visibility and add to the verge maintenance requirements. There is evidence to suggest that a gentle right hand bend leading to a left hand deflection at entry is more safe than a gentle left hand bend.

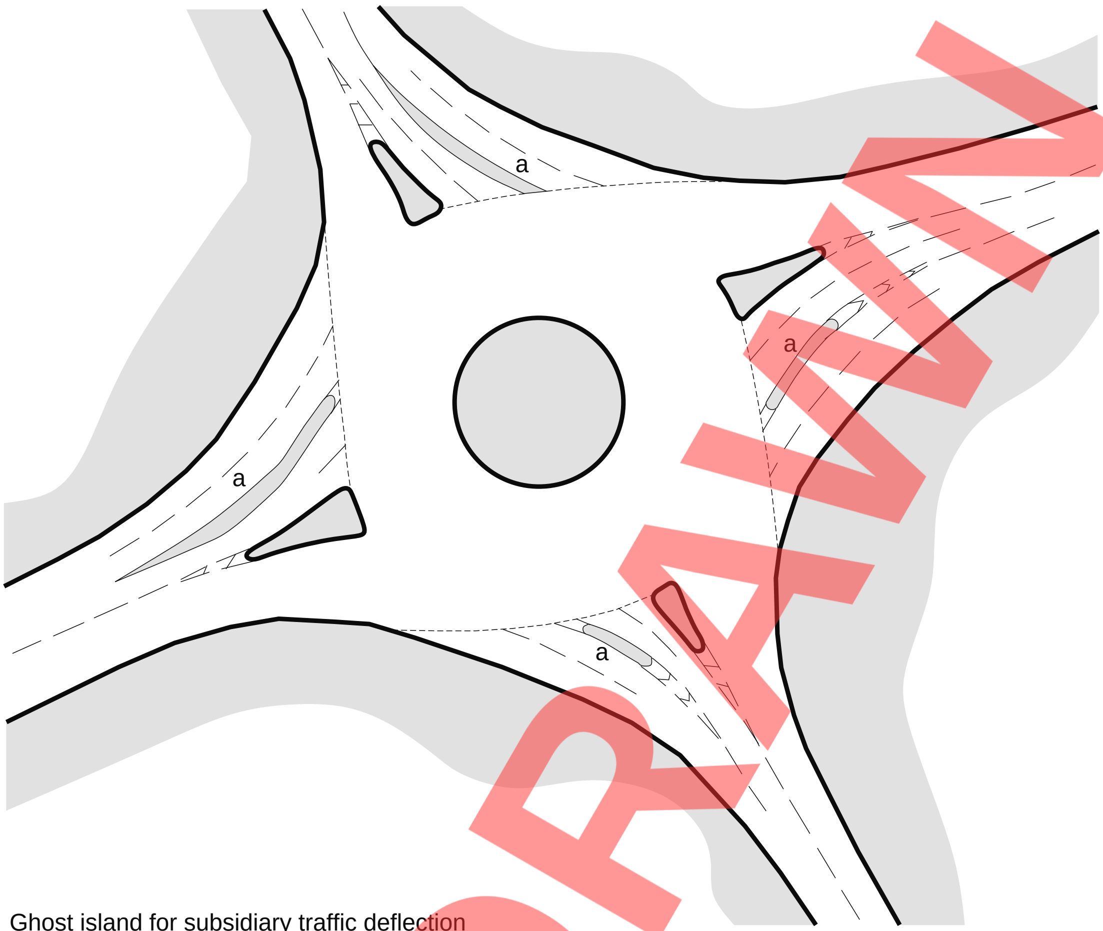
7.35 In urban areas, the restrictions on space available coupled with the turning width requirements of large goods vehicles may necessitate small normal roundabouts which cannot provide sufficient entry deflection to the left by means of the central island alone. In these cases deflection should be generated by means of enlarged traffic islands or by subsidiary traffic deflection ghost islands in the entry, (Figs 7/17 and 7/18).

7.36 Subsidiary Deflection Ghost Islands are areas defined by road markings, flush with the road surface. They should not be kerbed or raised. The conspicuity of subsidiary traffic deflection islands should be improved by surfacing the area in white reflectorised material. To highlight the perimeter during the hours of darkness, reflecting road studs should be affixed to the carriageway surrounding the islands along the alignment of the warning line. Care must be taken in the design of subsidiary islands to avoid any confusion with the primary traffic deflection island.



Example Showing how Deflection Island Design can Increase Entry Deflection at an Existing Roundabout

Figure 7/17



a Ghost island for subsidiary traffic deflection

Entry Deflection Achieved by Subsidiary Traffic Deflection Islands

Figure 7/18

Visibility

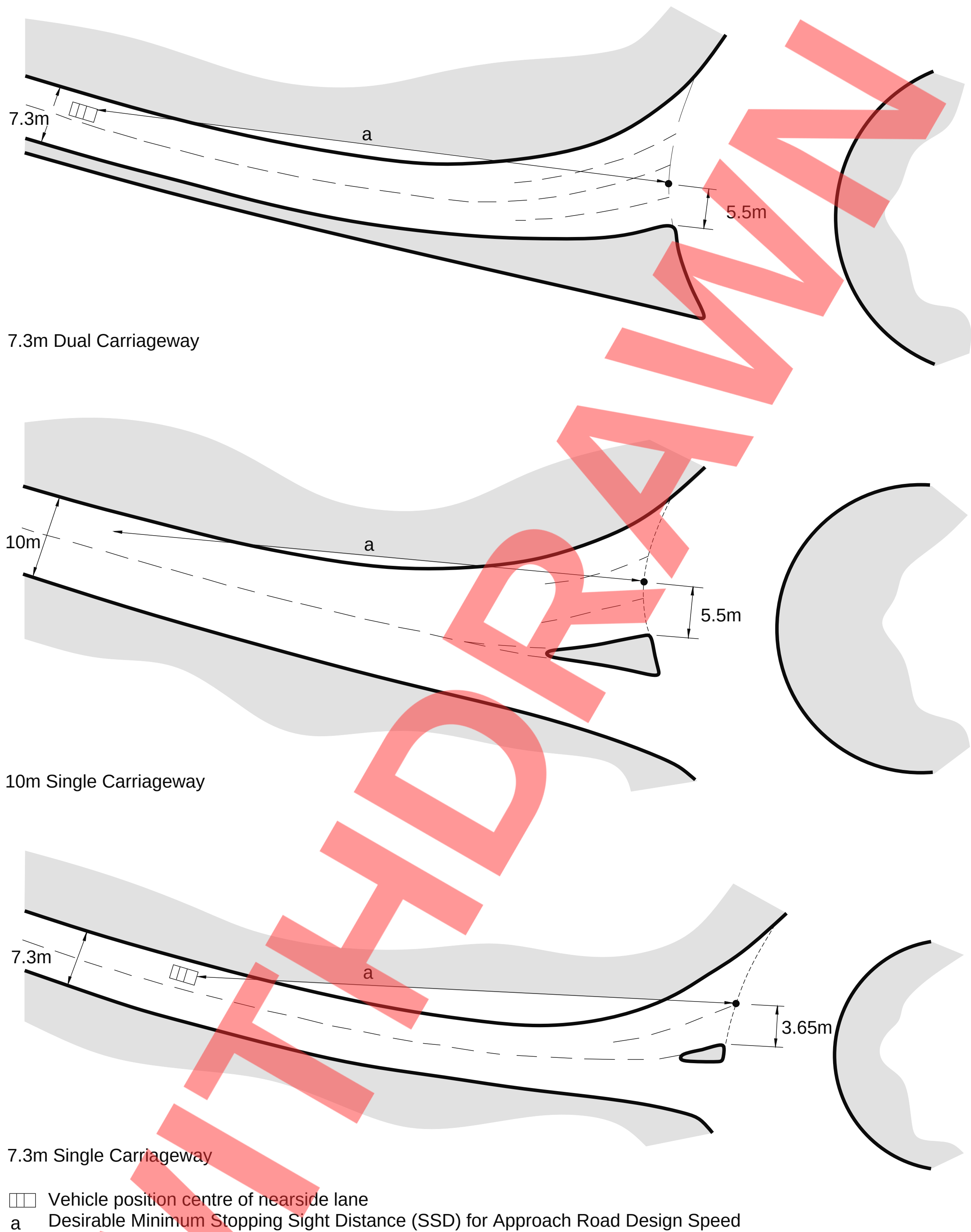
7.37 The forward visibility at the approach to a roundabout shall be as laid down in TD 9 (DMRB 6.1.1) measured to the "Give Way" line as shown in Fig 7/19.

7.38 The following guidelines represent good practice concerning the provision of visibility and, when subject to relaxation, there is a need for additional signing to alert drivers of all vehicles to potential hazards.

Eye and Object heights

7.39 Visibilities, with the exception of visibility to the right at entry and across the central island, shall be assessed in accordance with TD 9 (DRMB 6.1.1). Visibility to the right and across the central island shall be obtainable from a driver's eye height of 1.05m to an object height of 1.05m, and the envelope of visibility shall extend to 2.0m above the road surface.

7.40 Where traffic and direction signs are to be erected on a central reservation, verge, or deflection island within the envelope of visibility, including to the right, the mounting height shall not be less than 2.0m above the carriageway surface and the envelope checked on sites with changes of gradient.



Measurement of Stopping Sight Distance
Figure 7/19

Visibility to the Right

7.41 Drivers of all vehicles approaching the "Give Way" line shall be able to see the full width of the circulatory carriageway to their right, from the "Give Way" line for a distance appropriate to the sight stopping distance for the circulatory traffic (measured along the centre line of the circulatory carriageway) as indicated in Table 7/1, and shown in Fig 7/20a. This also applies to roundabouts that have parapet walls on either side of the ciculatory carriageway.

7.42 This visibility shall be checked from the centre of the offside lane at a distance of 15m back from the "Give Way" line, as shown in Fig 7/20b. Checks shall be made that crossfall design or construction and sign location do not restrict visibility.

7.43 It should be noted that excessive visibility at entry or visibility between adjacent entries can result in approach and entry speeds greater than desirable for the junction geometry. Consideration shall be given to limiting in particular the visibility of adjacent entries to that from 15m back on the approach, and the visibility along the approach to no more than the stopping sight distances for the design speed of the approach, by the selective use of landscaping.

Forward Visibility at Entry

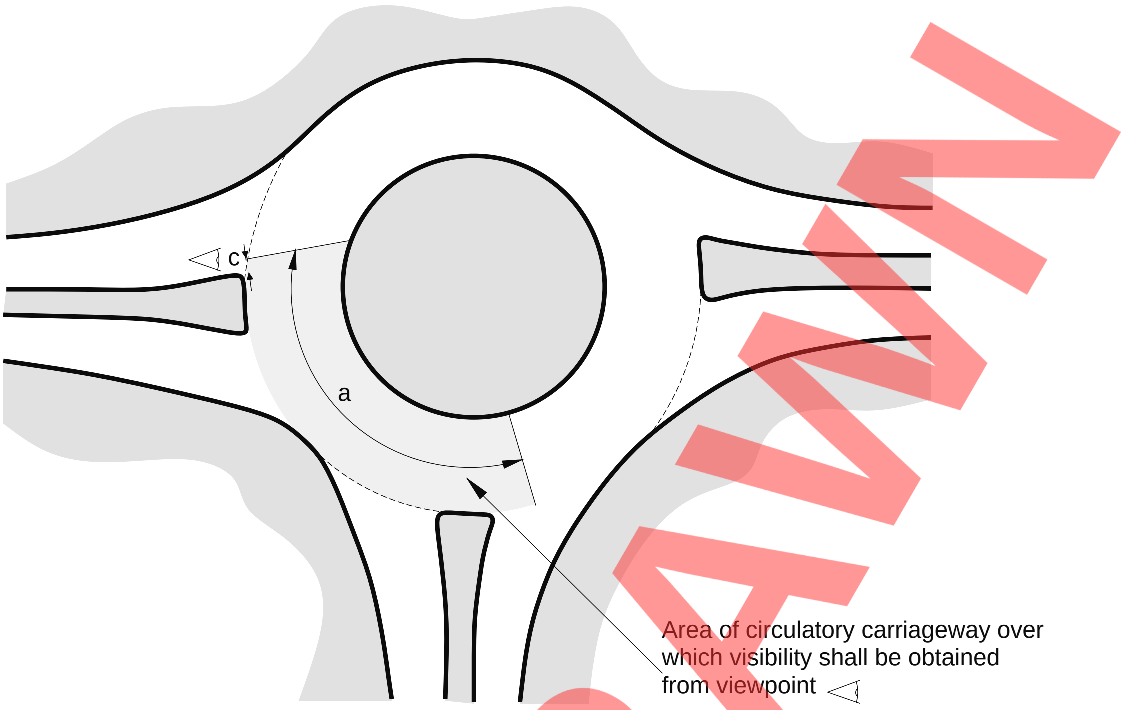
7.44 Drivers of all vehicles approaching the "Give Way" line shall be able to see the full width of the circulatory carriageway ahead of them for a distance (measured along the centre line of the circulatory carriageway) appropriate to the size of the roundabout (as indicated in Table 7/1). The visibility shall be checked from the centre of the nearside lane at a distance of 15m back from the "Give Way" line as shown in Fig 7/21.

Circulatory Visibility

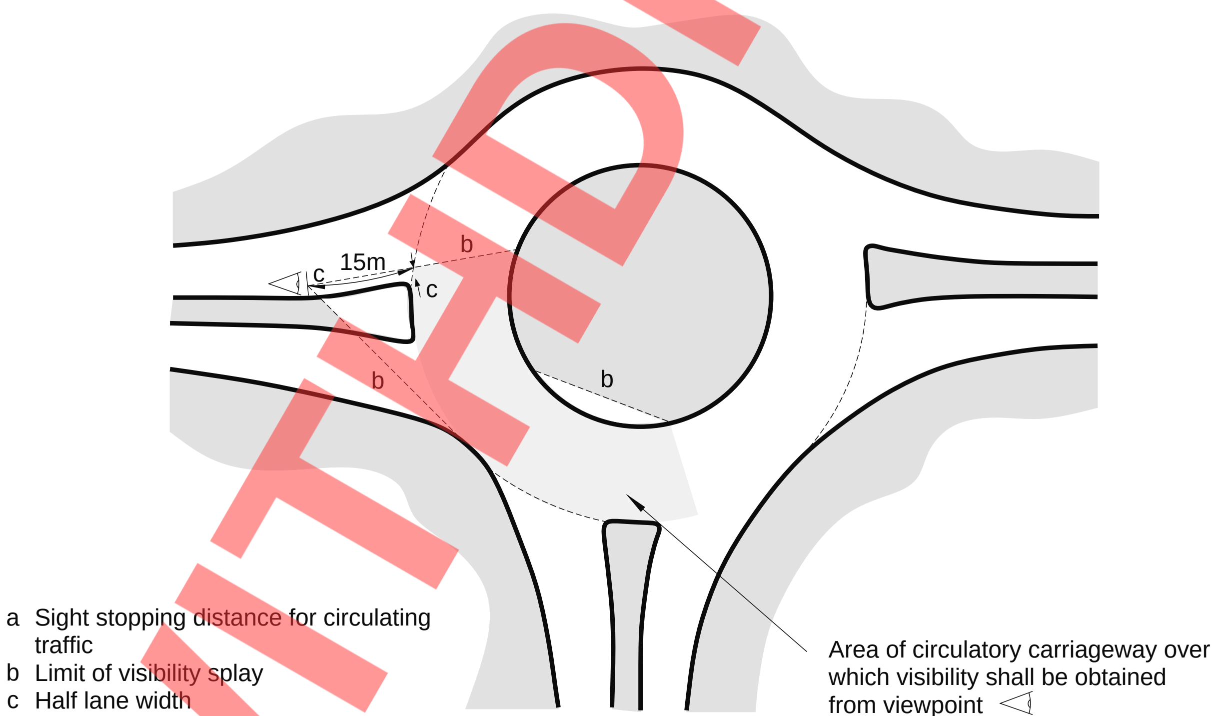
7.45 Drivers of all vehicles circulating on a roundabout shall be able to see the full width of the ciculatory carriageway ahead of them for a distance appropriate to the size of roundabout (as indicated in Table 7/1). This visiblity shall be checked from a point 2m in from the central island as shown in Fig 7/22. It is often useful to improve the conspicuity of central islands by the use of landscaping but this could obstruct circulatory visibility. The circulatory visibility envelope will encroach onto the height of vegetation or surface treatment. In these situations, limited penetration into the visibility envelope by vegetative growth of a dispersed nature would not be unacceptable.

Inscribed Circle Diameter (m)	**Visibility Distance (m) ("a" in Fig 7/20a)**
< 40	Whole junction
40-60	40
60 - 100	50
> 100	70

Table 7/1

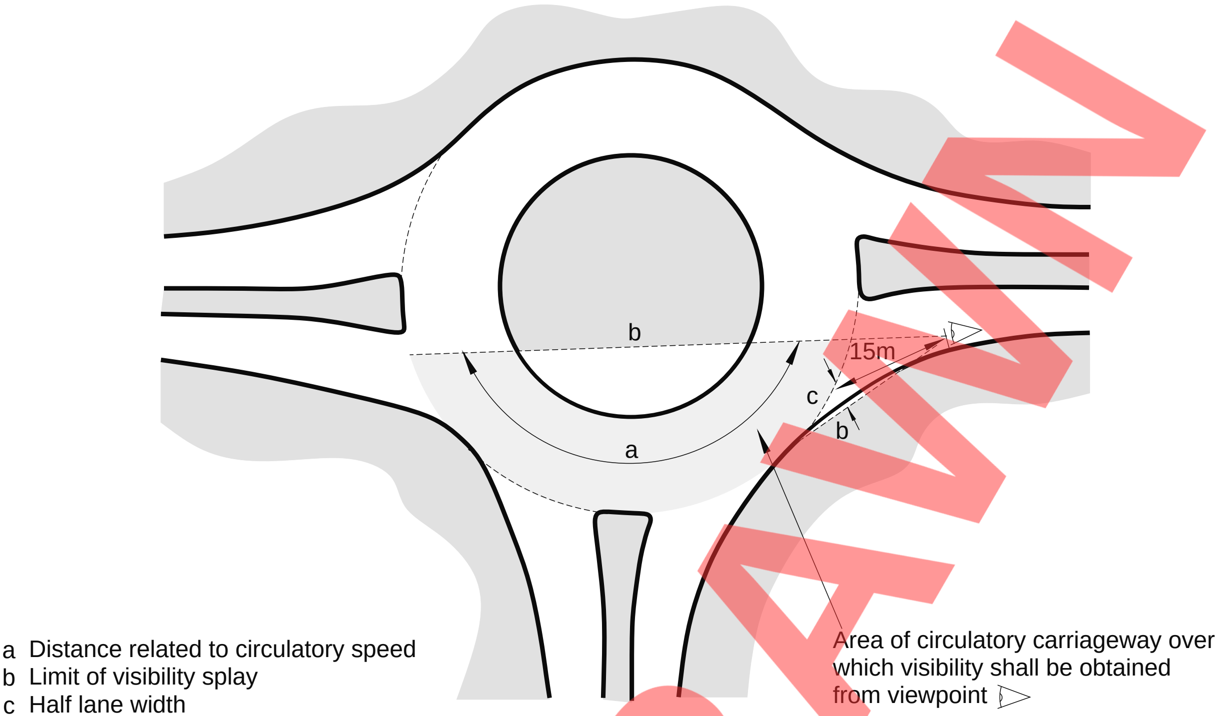


Visibility to the Right Required at Entry (from Give Way line)
Figure 7/20a



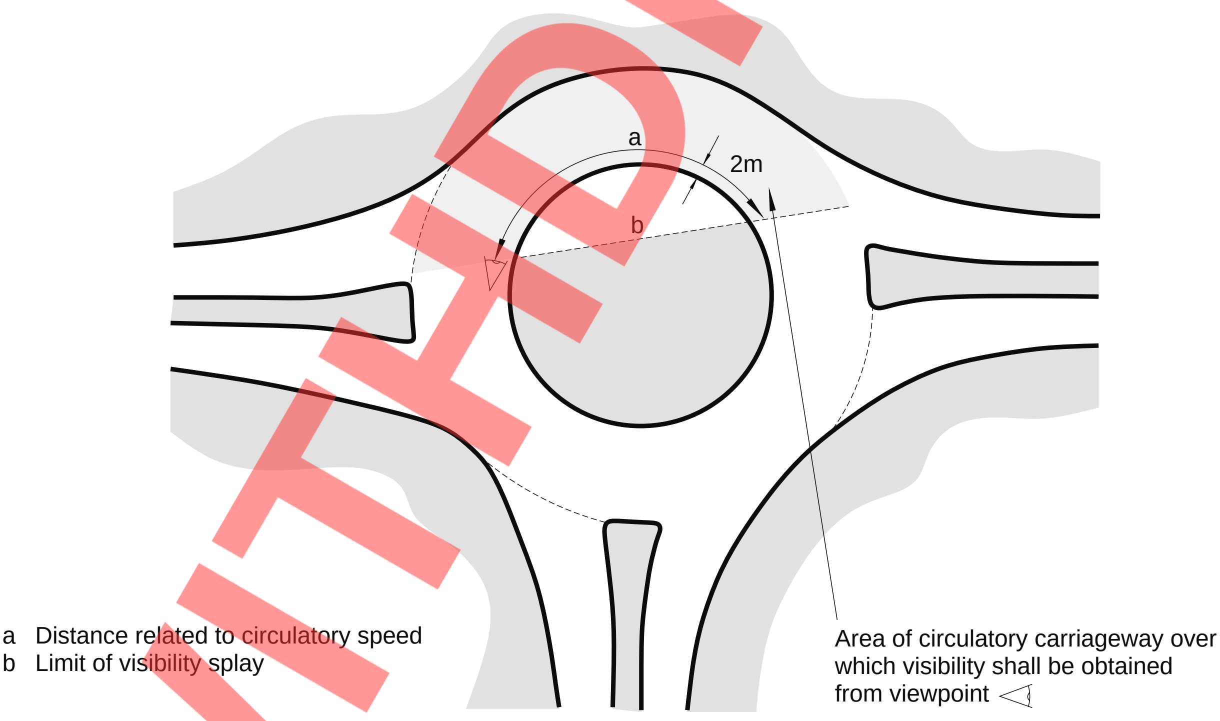
Visibility to the Right Required at Entry (15m back from Give Way line)

Figure 7/20b



Forward Visibilty Required at Entry

Figure 7/21



Circulatory Visibility

Figure 7/22

Pedestrian Crossing Visibility

7.46 Drivers of all vehicles approaching a pedestrian crossing across an entry shall have a minimum distance of visibility to it of Desirable Stopping Sight Distance for the design speed of the link. See TD 9 (DMRB 6.1.1). At the "Give Way" line, drivers of all vehicles shall 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 Fig 7/23). In urban areas, adjacent roadside development may however prevent this visibility splay being fully established.

Visual Intrusions

7.47 Signs, street furniture and planting shall not be placed within the visibility envelopes so as to obstruct visibility, but infringements by isolated slim projections such as lamp columns, sign supports or bridge columns can be ignored provided they are less than 550mm wide. The only exception to this will be positioning of bollards on deflection islands and staggered chevron boards on central islands (para 4.5a). Where possible, footways should be located outside visibility envelopes but where this is not possible care shall be taken to minimise the effects of pedestrians on visibility requirements.

Visibility at Grade Separated Junctions

7.48 Where roundabouts are above the main through route, it is most important to provide visibility at the slip road entries. Layouts shall be checked at the initial design stage to ensure that entry visibilities will not be obstructed by safety fences, barriers, bridge parapets or other features. Hatching out on the outside of roundabouts can be used to advantage to improve the situation where visibility for traffic entering from slip roads is limited. This can serve to achieve safer operation at dedicated left turn lanes from entry slip roads. If a roundabout is part of a flyover junction, the flyover abutments shall be set back to provide the recommended visibilities at the slip road entries. Otherwise severely restricted visibilities of this nature at entries usually generate delays and cause accidents. It is important that the "give way" line is clearly visible to approaching drivers and is not obscured by a vertical curve formed in the road surface. This can be achieved by the provision of a short length, say 10m, of level approach road immediately prior to the "give way" line.

Circulatory Carriageway

7.49 The circulatory carriageway should, if possible, be circular in plan, avoiding deceptively tight bends as referred to in para 4.13b and shown in Fig 4/1.

7.50 The width of the circulatory carriageway shall not exceed 15m.The largest Inscribed Circle Diameter (ICD) for a mini roundabout shall be 28m.

7.51 The width of the circulatory carriageway shall be constant and lie between 1.0 and 1.2 times the maximum entry width. However, see para 7.58 if small Inscribed Circle Diameters (ICDs) are being contemplated.

7.52 It is normal practice to avoid short lengths of reverse curve between entry and adjacent exits by linking these curves or joining them with straights between the entry radius and the exit radius. One method is to increase the exit radius. However, where there is a considerable distance between the entry and the next exit, as at three entry roundabouts, reverse curvature may result. (See Fig 7/20).

7.53 There may be situations where the turning proportions are such that one section of circulatory carriageway will have a relatively low flow. In this case there may be an over provision in circulating carriageway width and an area of carriageway, usually adjacent to an entry deflection island, becomes unused. It would be possible to reduce the circulatory carriageway width by extending the deflection island and advancing the give way line. This method of reducing circulatory width may also be adopted as an interim measure in the early years of a scheme.

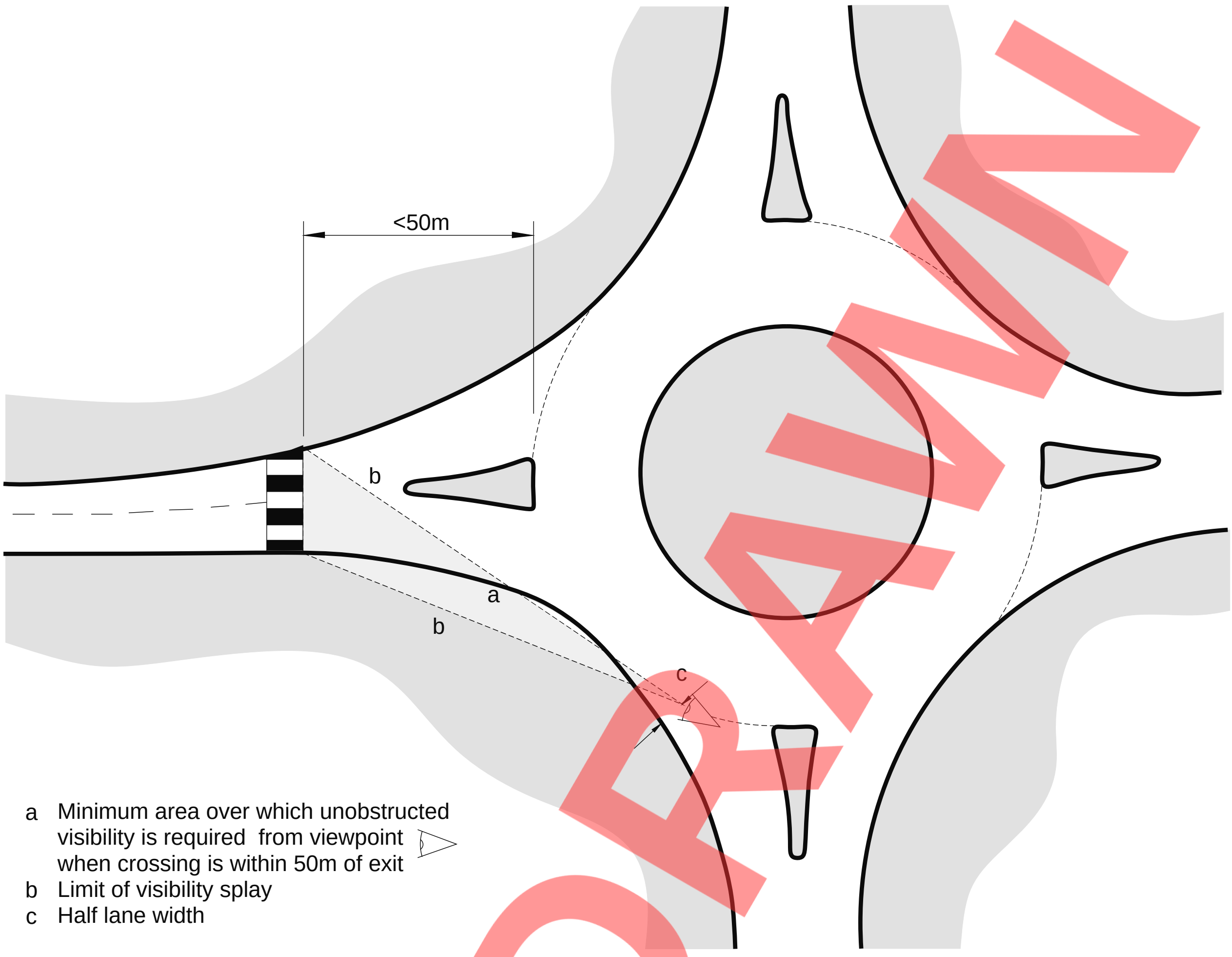


Figure 7/23 : Visibility Required at Entry to Pedestrian Crossing at next Exit

7.54 For larger roundabouts this reduction in circulatory width can be achieved by the use of hatch markings and is often associated with taking out of use the offside entry lane. If such measures are to be considered as an interim geometric design feature for early years traffic flows, consideration should be given to the use of contrasting hard surfacing for these areas.

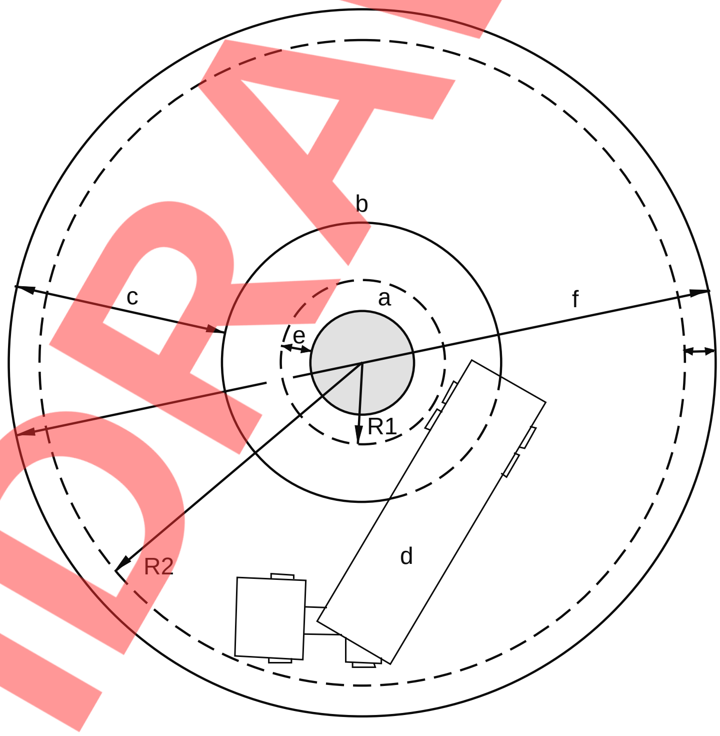
7.55 For smaller roundabouts it is more appropriate to consider interim circulatory carriageway reduction by increasing the size of the central island. If this is to be introduced from the outset a preferable measure would be the use of contrasting hard surfacing but hatch markings could also be considered.

Inscribed Circle Diameter (ICD)

7.56 The following advice is based on the swept turning paths generated by a 15.5m long articulated vehicle with a single axle at the rear of the trailer. This is referred to below as the "Design Vehicle". The turning width required by this type of vehicle is greater than that for all other vehicles within the normal maximum dimensions permitted in the current Vehicle Construction and Use Regulations, or likely to be permitted in the near future. The requirements for other vehicles (including an 11m long rigid vehicle, 12m long coach, 18.35m drawbar-trailer combination, and a 16.5m articulated vehicle) are less onerous.

7.57 The smallest ICD for a normal roundabout that will accommodate the "Design Vehicle" is 28m. If this cannot be accommodated, a mini roundabout should be used. It should be noted that it may be difficult, if not impossible, to meet the entry deflection requirement with normal roundabouts which have ICDs up to 40m. In this case consideration could be given to the installation of a low profile central island which would provide adequate deflection for standard vehicles but allow overrun by the rear wheels of articulated vehicles and trailers. Such islands should have the same profile as the circulatory carriageway with a maximum upstand of 50mm.

7.58 The turning space requirements for the "Design Vehicle" at normal roundabouts from 28m to 36m ICD are shown in Fig 7/24. For ICDs above these values, and/or where low profile central islands are to be installed the circulatory carriageway width should be checked against TA 20 (DMRB 6.2). But usually the rule in para 7.51 will provide more than adequate width.



a Main central island
b Low profile subsidiary central island where provided
c Remaining circulatory carriageway width 1.0-1.2 x maximum entry width.
d Design vehicle
e 1m clearance minimum
f Inscribed Circle Diameter

In these cases no entry deflection islands should protude within the ICD.

Central Island Diameter (m)	R1(m)	R2(m)	Minimum ICD (m)
4.0	3.0	13.0	28.0
6.0	4.0	13.4	28.8
8.0	5.0	13.9	29.8
10.0	6.0	14.4	30.8
12.0	7.0	15.0	32.0
14.0	8.0	15.6	33.2
16.0	9.0	16.3	34.6
18.0	10.0	17.0	36.0

Turning Widths Required for Smaller Normal Roundabouts

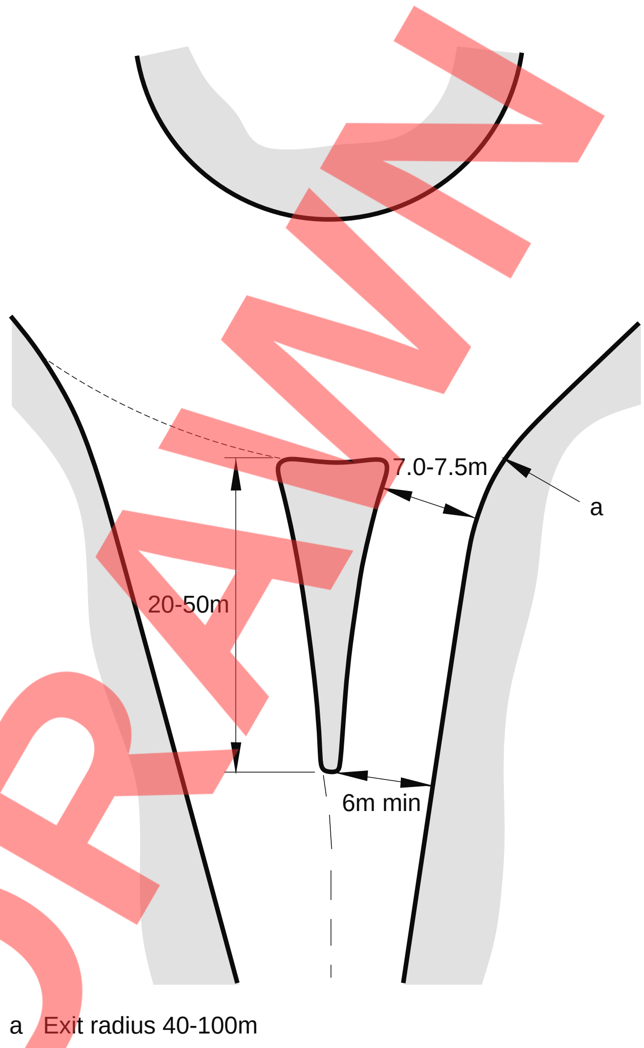
Figure 7/24

Exits

7.59 The spacing of an exit and the preceding entry shall not be less than that which results from the combination of the minimum entry radius (6m) and the minimum exit radius (20m), though desirable radii of 20m, and 40m respectively should be used where possible. If an existing roundabout is to be modified to include an additional entry, care must be taken to ensure that this does not affect safety at the preceding entry and following exit. It may be necessary to redesign the whole junction if adequate spacing between adjacent entry/exit cannot be achieved.

7.60 The principle of "easy exits" shall be applied. A nearside kerb radius of about 40m at the mouth of the exit is desirable but for larger rural roundabouts this may be increased to suit the overall junction geometry. In any case, this radius shall not be below 20m or greater than 100m.

7.61 At the beginning of an exit, its width, measured normally to the exit radius, should, where possible, allow for an extra traffic lane over and above that of the link downstream. For example, if the downstream link is S2 or WS2 the width at the exit should be 7.0m or 7.5m, and if the link is D2AP, the width should be 10m to 11m. This extra width should be reduced on the nearside in such a way as to avoid exiting vehicles encroaching onto the entering carriageway at the end of the traffic deflection island. Normally, this would be at a taper of 1:15 to 1:20, though where the exit is on an up gradient, the local widening may be extended to reduce intermittent congestion from slow moving larger vehicles and to provide an overtaking opportunity for faster vehicles. Similarly, if the exit road is on a left hand curve it may be necessary to extend the taper length and the length of the traffic deflection island. Within single carriageway exits, a minimum width of 6m, measured normally to the nearside kerb, should be provided adjacent to traffic deflection islands to allow traffic to pass a broken down vehicle. Fig 7/25 shows a typical single carriageway exit embodying some of the above principles. On exits the edge line should continue along the line of the kerbing once this is terminated. (See Figs 7/9 and 7/10)



Typical Single Carriageway Exit
Figure 7 / 25

Crossfall and Longitudinal Gradient

7.62 Steep gradients should be avoided at roundabout approaches or flattened to a maximum of 2 per cent before entry. Crossfall and longitudinal gradient combine to provide the necessary slope that will drain surface water from the carriageway. Thus, although the following paragraphs are for simplicity written in terms of crossfall, the value and direction of the greatest slope must always be taken into account when considering drainage. It may well be that large or elongated roundabouts may have to be designed using steeper gradients within them in line with TD 9 (DMRB 6.1.1) in order to meet environmental concerns. Superelevation is arranged to assist vehicles when travelling round a curve. Its values, when used, are equal to or greater than those necessary for surface water drainage.

7.63 Superelevation is not required on the circulatory carriageways of roundabouts whereas crossfall is required, to drain surface water, but on the approaches and exits superelevation can assist drivers to negotiate the associated curves.

7.64 Normal crossfall for drainage on roundabouts should be 2 per cent (1 in 50). Crossfall should not exceed 2.5 per cent (1 in 40). To avoid ponding, longitudinal edge profiles should be graded at not less than 0.67 percent (1 in 150), with 0.5 per cent (1 in 200) considered the minimum. The design gradients do not in themselves ensure satisfactory drainage, and therefore the correct siting and spacing of gullies is critical to efficient drainage.

For Entries

7.65 Here, curves may be tightened, (see para 7.34) and the degree of superelevation should be appropriate to the speed of vehicles as they approach the roundabout but superelevation should not exceed 5% (1 in 20). In cases where superelevation is used, it should be reduced to the crossfall required merely for drainage in the vicinity of the "Give Way" line, since with adequate advance signing and entry deflection, speeds on approaches should be reducing.

For Circulatory Carriageway

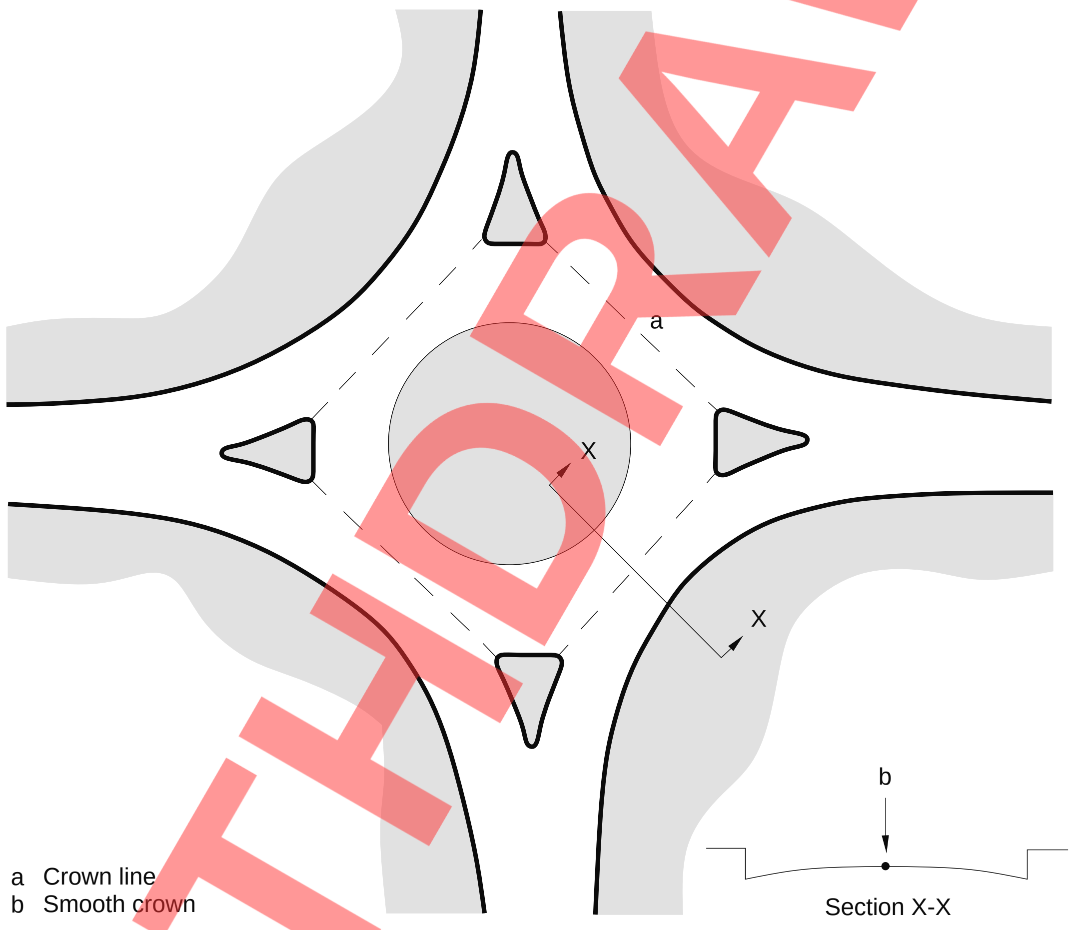
7.66 Values of crossfall should be no greater than those required for drainage, although it is good practice at normal roundabouts, to arrange for crossfall to assist vehicles. To do this, a cross line is formed where the entry and exit carriageways meet the conflicting crossfall of the circulatory carriageway. This line can either join the end of the traffic deflection islands from entry to exit (Fig 7/26), or divide the circulatory carriageway in the proportion 2:1 internal to external (Fig 7/27). In some cases a subsidiary crown line may assist in achieving appropriate values of crossfall without giving excessive changes at the main crown line (Fig 7/28). The conflicting crossfalls at the crown lines have a direct effect on driver comfort and may also be a contributory factor in load shedding and large goods vehicle roll-over accidents. The maximum recommended algebraic difference in crossfall is 5 per cent although lesser values are desirable, particularly for roundabouts with smaller ICD. Care needs to be taken during detailed design and at the construction stage to ensure a satisfactory carriageway profile, without sharp changes in crossfall, is achieved. A smoothed crown is essential. In some cases with small ICDs it may be more appropriate to apply crossfall across the full circulatory carriageway width either towards the central island or away from it. This should only apply where vehicle speeds are relatively low.

For Exits

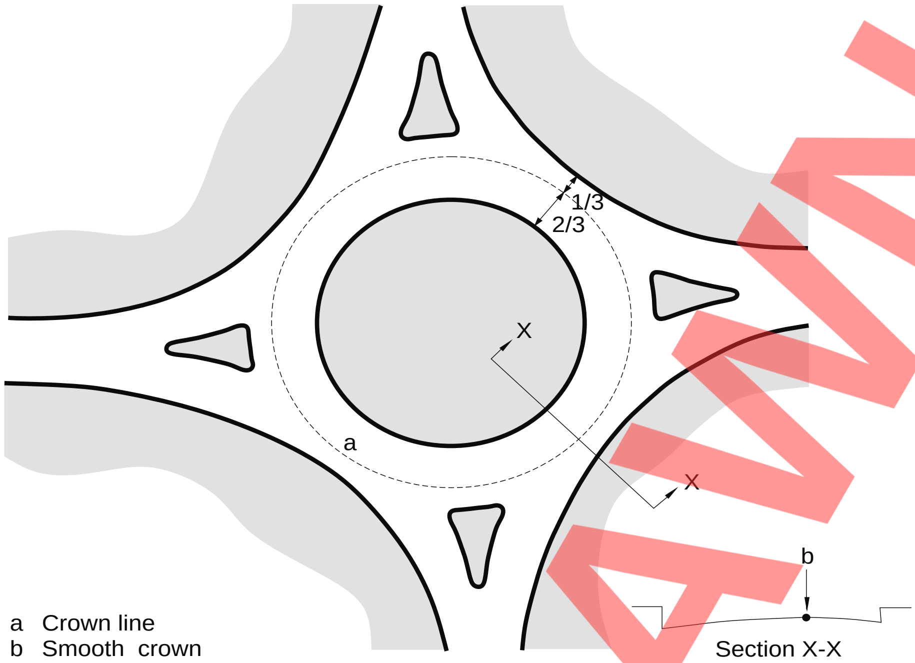
7.67 Superelevation, related to the horizontal alignment, should be provided where necessary to assist vehicles to accelerate safely away from the roundabout. However, as with entries, crossfalls adjacent to the roundabout should be those required for surface water drainage. If the exit leads into a right hand curve, superelevation should not be introduced too quickly and to such a value that vehicles tend to encroach into an adjacent (dual or opposing single carriageway) lane.

Adverse Crossfall

7.68 Adverse Crossfall is crossfall that acts against the desired movement of a vehicle when turning. It can lead to driver discomfort and even safety hazards and should, if possible, be eliminated from the paths of the main traffic movements at normal roundabouts. Mini roundabouts and smaller normal roundabouts in urban areas are often superimposed upon existing pavement profiles and in these cases, the cross section of the existing roads will influence crossfalls at the roundabout. T-junctions require particular attention. Some adverse crossfall can be accepted in order to fit the existing levels provided approach speeds are low. Limited adverse crossfall at mini roundabouts can assist in making the form of junction more conspicuous to drivers.

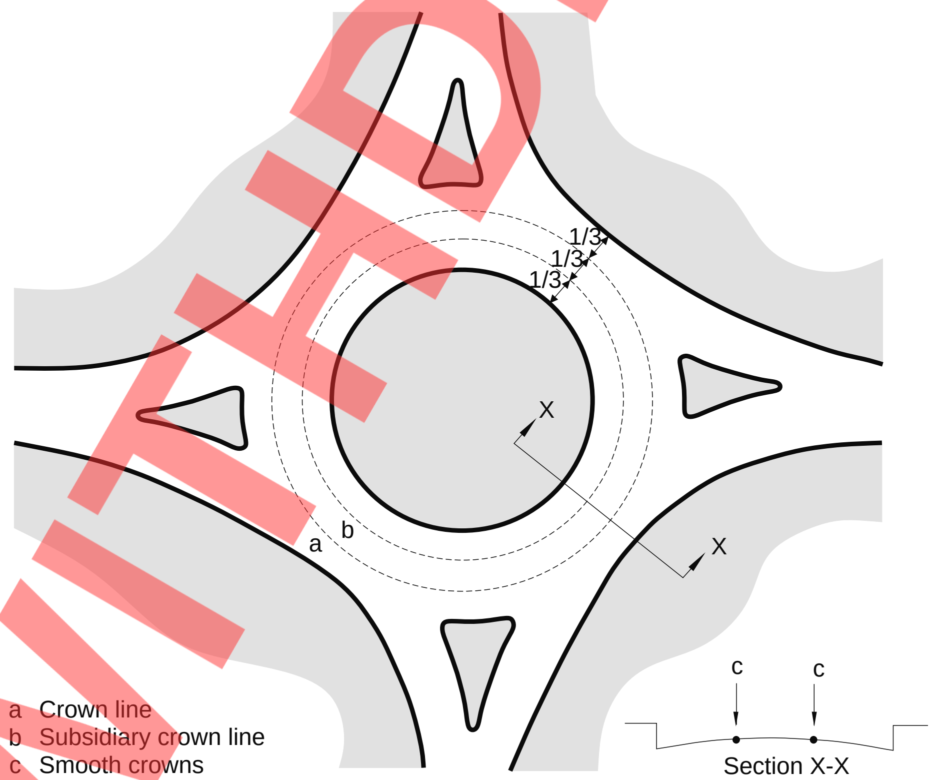


Typical example of Crossfall Design Using One Crown Line which Joins the Traffic Deflection Islands by Straight Lines - Figure 7 / 26



Typical Example of Crossfall Design Using One Crown Line which Divides the Circulatory Carriageway in the ratio 2:1

Figure 7 / 27



Typical Example of Crossfall Design Using Two Crown Lines
Figure 7 / 28

Segregated Left Turning Lanes

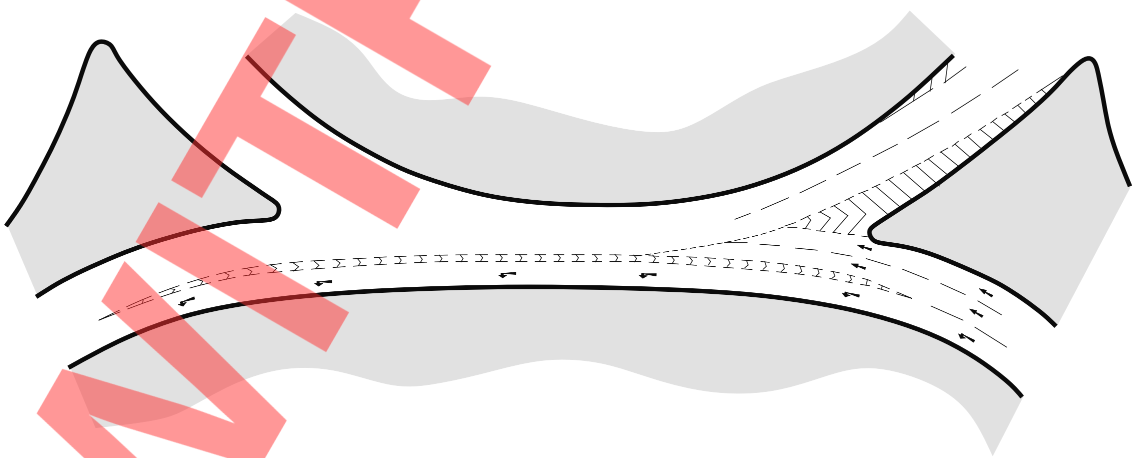
7.69 Segregated left turn lanes are a useful method for giving an improved service to vehicles intending to leave a roundabout at the first exit after entry. Their use should be considered when more than 50 per cent of the entry flow, or more that 300 vehicles per hour in the peak hours, turn left at the first exit. However, when considering the use of these lanes, vehicle composition should be examined. If the left turn vehicles are predominantly light and there is a high proportion of cyclists and/or large goods vehicles leaving the roundabout there could be problems with differential speeds at the merge, particularly if this is on an uphill gradient. If segregated lanes are to be used in these situations they should finish with a "Give Way" line at the exit to the lane.

7.70 The use of these lanes in urban areas where pedestrians are expected to cross should be carefully considered. In no circumstances should pedestrians be expected to cross left turn lanes segregated by road markings. If pedestrians are anticipated they should be channelled with the use of guard rail to a safer crossing point. If this is not possible the segregation should be by a physical island of sufficient width to accommodate the anticipated peak number of pedestrians.

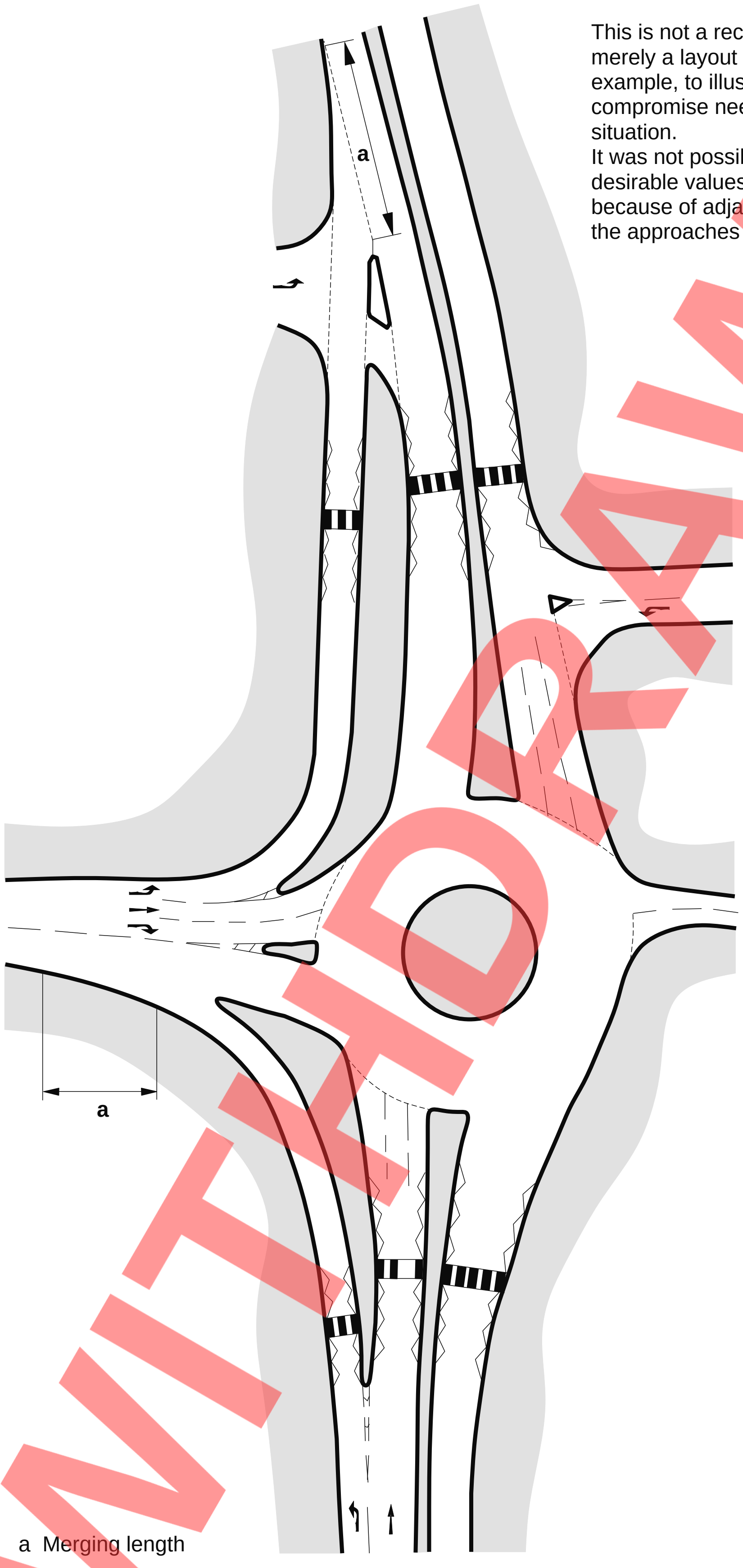
7.71 There are two basic types of segregated left turn lanes, namely segregation by road markings as shown in Fig 7/29 and physical segregation as shown in Fig 7/30. In both types vehicles are channelled into the left hand lane by lane arrows and road markings, supplemented by advance direction signs, and vehicles proceed to the first exit without having to give way to others using the roundabout. Segregation by road markings is more common, but is less effective because it is subject to abuse. It is essential that the operation of the segregated lane is not impaired by traffic queuing to use the roundabout itself. The designer should ensure that the approach arrangements are sufficiently clear so that they are relatively self-enforcing.

7.72 Segregated left turn lanes should not induce high speeds. The design speed should not exceed that of either the entry or exit link, and any desirable speed reduction should be achieved at the entry to the lane rather than within it. Forward visibility throughout the segregated lane should be the appropriate stopping site distance for the design speed. Where the large goods vehicle proportion is low the lane width may be reduced to 3.5m but should not be less than 3.3m. Where road markings are used to create the lane segregation, the overall width of the marking should normally be a minimum of 1.0m. Where the large goods vehicle content is higher the lane width must be checked to ensure that it can accommodate the swept paths of larger vehicles, especially where physical segregation occurs. Further information on the widening of lanes on curves is given in TA 20 (DMRB 6.2).

7.73 It is not necessary to make allowance for broken down vehicles with segregation by road markings. Such vehicles can be overtaken with caution. Where physical segregation is introduced this should not prevent a left turn at the roundabout in the normal way from the non segregated part of the approach.



Typical Example of a Segregated Left Turning Lane Using Road Markings
Figure 7/29



Physically Segregated Left Turning Lanes : an Existing Urban Compromise
Figure 7/30

7.74 These lanes have been observed to handle 1300 vehicles per hour with ease and for design purposes a maximum capacity of 1800 light vehicles per hour may be assumed where the exit is free running. Segregated lanes need not be considered as part of the entry when calculating capacities for other traffic movements.

7.75 The merging between vehicles from a segregated left turn and other vehicles exiting the roundabout should take place within 50m of the roundabout, where speeds are still comparatively low. Ideally there should not be a forced merge. However, running the two streams alongside each other is only possible where the exit link can provide two lanes in the same direction. In other cases the segregated left turning traffic has to merge with the other stream, giving way where necessary. This merging length should be at least 10m long. (See Fig 7/30). Segregation by road markings is not recommended if vehicles have to give way at the merge point. Where street furniture is placed on the island in the vicinity of the merge it should not obstruct visibility.

7.76 In the improvement of existing urban T-junctions, a layout such as shown in Fig 7/31 may be attractive in terms of land take. However, the signing on the segregated left turning lane must clearly indicate to drivers that they have to give way to vehicles leaving the roundabout.

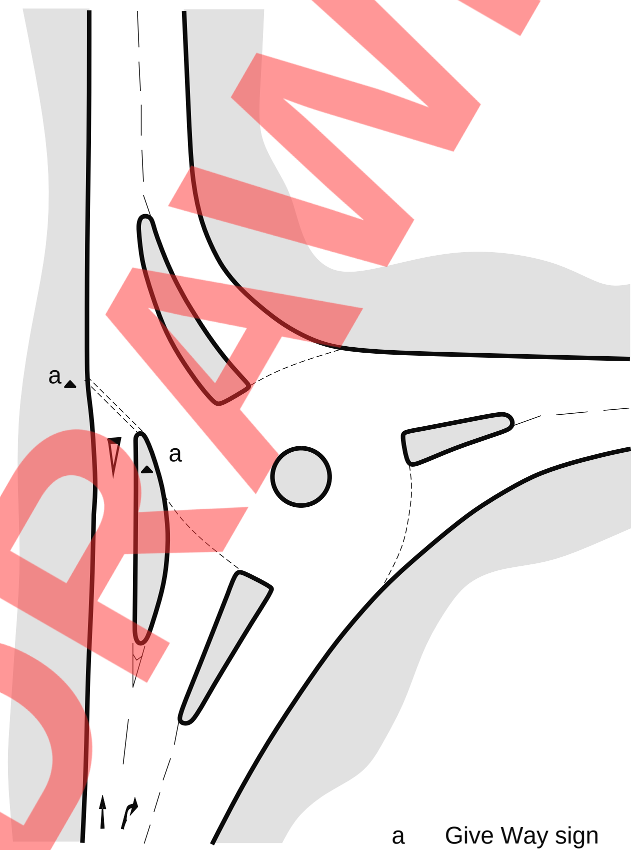
Road Markings

7.77 Road markings are used to channelise traffic and where required, to indicate a dedicated lane. Lane indication arrows to reinforce the advance map type direction signs at entries can be beneficial where heavy flows occur in a particular direction.

7.78 Lane dedication should not be used where entries are less than three lanes wide. Where any particular lane is dedicated the other lanes should also have arrow markings. This arrangement should always be accompanied by advance direction signing which indicates lane dedication.

7.79 Lane dedication by arrows and markings on the circulatory carriageway is not normally recommended. Where a roundabout is particularly extensive and partially signalled and it is tending to a gyratory system, then some degree of channelisation by road markings may prove beneficial operationally.

7.80 The dedication by direction arrows of an offside lane to a right turning movement should not be used at ferry ports with services to mainland Europe where large numbers of continental drivers are likely to be present. This is to avoid any confusion arising in visitors minds over which way to proceed around the roundabout.



This is not a recommendation, but merely a specific example showing the modification of a previous major/minor junction where it was not possible (because of site constraints) to provide desirable entry deflection on one approach. There are, however, speed limits on the approaches.

Very clear indication must be given to segregated left turning lane traffic regarding the need to give way to traffic leaving the roundabout.

'Straight Through' Segregated Left Turning Lane at 3 Way Roundabout

Figure 7/31

8. REFERENCES

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3. The Siting of Roundabouts

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c) TA 20 DMRB Volume 6, Section 2.

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9. ENQUIRIES

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CALCULATION OF ROUNDABOUT CAPACITIES

1. The formulae for capacity calculation for roundabouts evaluates the conflict between the traffic entering the roundabout and the circulating flow already on the roundabout. Iterative calculations are necessary to compute the various flows gaining entry against different circulating flows. The computer program ARCADY/3 has been developed to carry out these calculations and evaluate queues, delays and, in some cases, predict accident rates. "Entry Capacity" or "Capacity" at roundabouts is defined as the maximum inflow from an entry to a roundabout when the traffic flow at that entry is sufficient to cause continuous queueing in its approach road.

2. The equation for the prediction of entry flow into a roundabout as a function of the circulating flow and entry geometry, can be applied to all types of single at-grade roundabout whether mini or normal types. Having developed a range of Reference Traffic Flows (paragraph 6), a designer should use the equation to produce trial designs for assessment. The method of handling figures will depend on whether manual or computerised methods are used. It is not realistic to calculate queue lengths and delays manually, but this is a normal part of computer output.

The Ratio of Flow to Capacity

3. The ratio of flow to capacity (RFC) is an indicator of the likely performance of a junction under a future year traffic loading. It should be calculated for each trial design. Due to site-to-site variation, there is a standard error of prediction of the entry capacity by the formulae of + or - 15% for any site. Thus if an entry RFC of about 85% occurs, queueing will theoretically be avoided in the chosen design year peak hour in 5 out of 6 peak hour periods or sites. Similarly, if an entry RFC of 70% occurs, queueing will theoretically be avoided in 39 out of 40 peak hour periods or sites.

4. The general use of designs with an RFC of about 85% is likely to result in a level of provision which will be economically justified. There will be cases, however, where the adoption of a lower figure will be justified: for example, where the cost of a higher level of provision is low in both economic and environmental terms, or where space for enlargement is unlikely to be available in the future at a reasonable cost and thus the cost of being wrong becomes unreasonably high. On the other hand, if there are cost or environmental implications in providing higher capacity, for instance in urban areas, then even the 85% ratio may be unsuitable and a higher ratio, with consequent queueing, will have to be accepted (to an extent assessed by the reduction of economic or environmental impact)

5. Circumstances will vary, and it may often not be possible to provide the same RFC on all approaches, but the aim should be to achieve a reasonably balanced design in this respect. On the other hand, ratios higher than 85% could be used at some less important entries if exceptionally low ratios are unavoidable at others, though the possibility of excessive queueing at any entry should be avoided.

6. Designers should not strive to obtain a unique value. A range of situations must be considered and the advantages and disadvantages of each one assessed.

Variation

7. It must be stressed that the calculated capacities, queues and delays are average values of very broad distributions. The formulae used are based on multiple regression analyses from observations from a large number of sites. Actual values can vary about the average due to:

Site to site variation
Day to day variation.

Site to site variation has been estimated, and is covered by the procedures. As far as day to day variation is concerned this will manifest itself in practice as variations in the queue lengths and delays at any given time in the peak period. The formulae merely calculate the average values over many days. ARCADY/3 offers daily variability calculations as well as averages.

Roundabout Capacity Formula

8. The best predictive equation for the capacity of a roundabout entry (except those at grade separated interchanges, for which see paragraph 9), found by research to date is as follows:

$Q_e = k\,(F - f_c\,Q_c)$ when $f_c\,Q_c$ is less than or equal to F,

or

$Q_e = 0$ when $f_c\,Q_c$ is greater than F.

Where:

Q_e = entry flow in pcu/hour (1 HGV = 2 pcu)
Q_c = circulating flow across the entry in pcu/hour
$k = 1 - .00347(\phi - 30) - .978\,\{(1/r) - .05\}$
$F = 303\,x_2$
$f_c = .21\,t_p\,(1 + .2\,x_2)$
$t_p = 1 + .5/(1 + M)$
$M = \exp\{(D - 60)/10\}$
$x_2 = v + (e - v)/(1 + 2\,S)$
$S = 1.6\,(e - v)/l'$

The remaining parameters are defined at the start of Chapter 7 of the main document.

9. The above equation applies to all roundabouts except those at grade separated interchanges. For all entries at very large and grade separated roundabouts:

$Q_e = 1.004F - 0.036SEP - 0.232Q_c + 14.35 - F_c\,Q_c\,(2.14 - 0.023Q_c)$ where:

SEP = separation of exit and entry for grade separated approaches,
Q_c =mean circular flow for central 30 minutes.

These differences are incorporated in the ARCADY/3 program.

Manual Calculation

10. The RFC should be calculated using the formulae. The Design Reference Flows should be multiplied by 1.125 to allow for traffic flows. Short term variation is included in ARCADY/3.

Computerised Calculation

11. A computer program such as ARCADY/3 should be used. The appraisal can be based on either an RFC of 85% or, in certain cases, a higher or a lower ratio in the same way as described previously. In calculating this, a time segment length of not less than 5 minutes should be used to build up the flow pattern during the peak. The program prints out the RFC (labelled Demand/Capacity in the output), queue lengths and delays at each entry for each time segment. An inspection can therefore be made, for each arm in turn, of the queue length and delay if the RFC reaches 85% (or 70%).

Layout factors

12. The trial design should be adjusted where necessary to obtain operational efficiency or increased safety by adjusting the entry widths, the length of the flares, etc. The list in the following Table gives the normal practical limits of parameters for new design, compared with the range measured at roundabouts on which the capacity formulae are based.

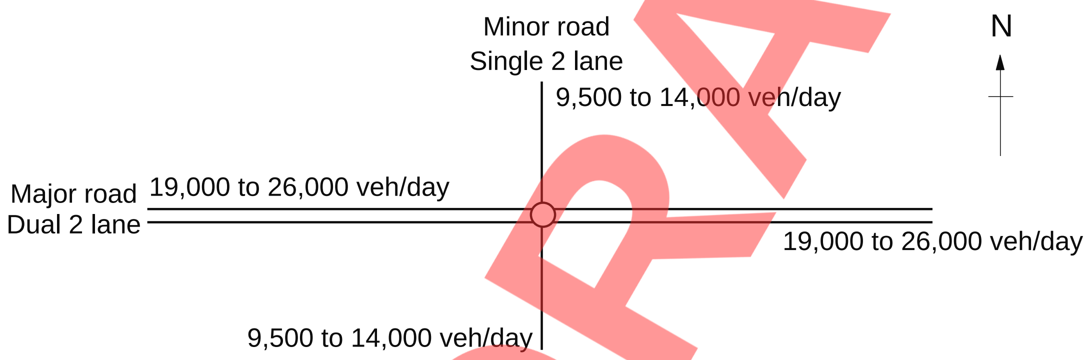
13. The following are two examples of typical calculations.

	Parameter	Practical Range	Measured Range
e	entry width	4 - 15m	3.6 - 16.5m
v	approach half width	2 - 7.3m	1.9 - 12.5m
l′	average effective flare length	1 - 100m	1 - 30m
S	sharpness of flare		0 - 2.9m
r	entry radius	6 - 100m	3.4 - infinity
ϕ	entry angle	10 - 60 °	0 - 77 °
D	inscribed circle diameter	15 - 100m	13.5 - 171.6m

Example 1

1. It has been decided to construct a roundabout at the junction between a D2AP road and a S2 road on the fringe of an urban area. Traffic flows are main urban in character with very low seasonal variation.

2. The traffic information available from the traffic model, this being an urban scheme, is the expected normal high growth and low growth 2-way 24 hour Annual Average Weekday Traffic (AAWT) flows on each road for the year 2010 (a year about 12 years after the expected opening date):-



24 hour AAWT 2-way flows.

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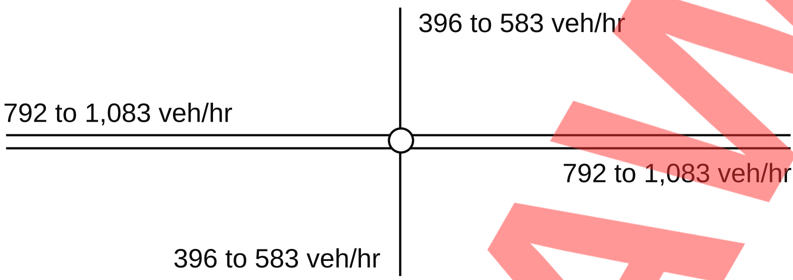
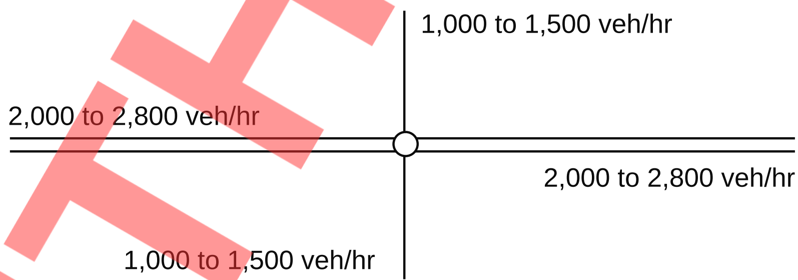
3. From the AAWT 2-way flows the Annual Average Weekly Hourly Traffic (AAWHT) 2-way flows on the approach roads in 2010 are calculated. AAWHT = AAWT/24, for example, 19000/24 = 792, 26000/24 = 1083, etc.



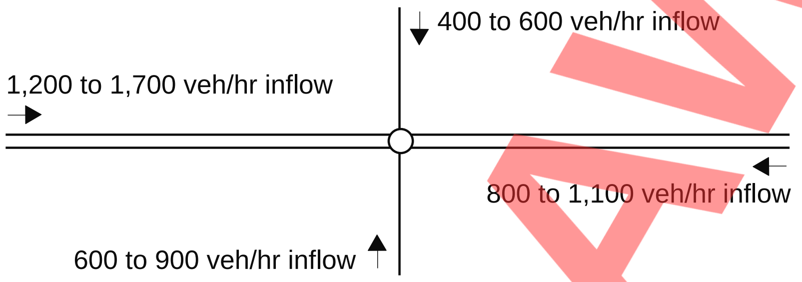
AAWHT 2-way flows.

4. As there is very low seasonal variation it has been decided in this particular case to use the estimate of the 30th highest hour in 2010 to obtain the 2-way flows on approach roads in the design peak hour. Thus AAWHT is factored by 2.547 (peak to average ratio) (see TAM). For example, 792 x 2.547 = 2017, say 2000, etc.



Design peak hour 2-way flows.

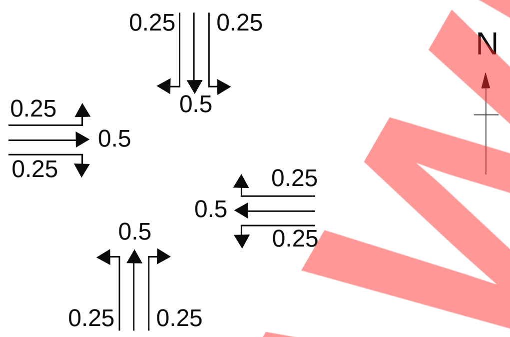
5. To obtain the directional flows (ie, the range of entry flows into the junction) from the design peak hour 2-way flows on the approach roads it has been decided in this case to assume a 60/40 split with the entry flows from the west and south dominant. For example, 200 x 0.6 = 1200; 2800 x 0.6 = 1680, say 1700; 200 x 0.4 = 800; etc.



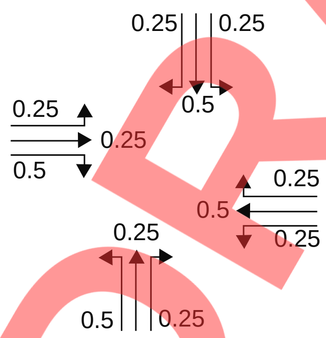
Directional flows.

6. Turning movements to and from the south are expected to dominate, and the following three patterns are expected to reflect the range of possibilities in the design peak hour.

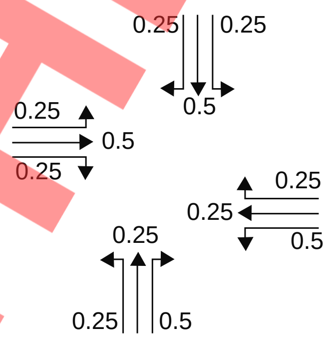
TM1



TM2



TM3



Directional flows when adjusted using turning proportions are termed "Design Reference Flows".

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7. The main design parameters for capacity are entry width, e, and average effective flare length, l′. An initial examination of the possibilities indicates the following ranges in this case.

ARM	e (m)	l′ (m)
SOUTH	3.65 - 12	about 10-50
WEST	7.3 - 15	about 10-50
NORTH	3.65 - 12	about 10-50
EAST	7.3 - 15	about 10-50

A preliminary screening indicates the most plausible alternatives as a 63m ICD and a 70m ICD roundabout with the following parameters: (Note the need for vehicle path deflection since the approach roads are derestricted).

63m ICD

ARM	v(m)	e(m)	l′(m)	t(m)	d(m)	ϕ degrees
SOUTH	3.65	7.30	25.0	20.0	63.0	30.0
WEST	7.30	10.50	25.0	20.0	63.0	30.0
NORTH	3.65	7.30	25.0	20.0	63.0	30.0
EAST	7.30	10.50	25.0	20.0	63.0	30.0

70M ICD

ARM	v(m)	e(m)	l′(m)	t(m)	d(m)	ϕ degrees
SOUTH	3.65	10.5	25.0	20.0	70.0	30.0
WEST	7.30	13.0	25.0	20.0	70.0	30.0
NORTH	3.65	10.5	25.0	20.0	70.0	30.0
EAST	7.30	13.0	25.0	20.0	70.0	30.0

8. The trial layouts are assessed for peak hour performance over the range of design Reference Flows using the ARCADY/3 program. The results shown overleaf indicate maximum RFCs, queue lengths and delays that can be expected. At high growth, RFCs for the 63m ICD roundabout reach 97-98%, while the corresponding figures for the 70m ICD roundabout are 85%.

Traffic being appraised	Range of Reference flows (v.p.h.)		Checks on R.F.C.s, queue lengths and delays for trial designs: 63m ICD 3 lane entry D2 2 lane entry S2	Checks on R.F.C.s, queue lengths and delays for trial designs: 70m ICD 4 lane entry D2 3 lane entry S2
LOW GROWTH	1,200 → ↓ 400 600 ↑ ← 800	TM 1	61%.2.4 → ↓ 41%.1.5 51%.1.5 ↑ ← 40%.1.3	54%.1.3 → ↓ 32%.0.4 41%.1.4 ↑ ← 35%.1.2
		TM 2	58%.1.3 → ↓ 41%.1.5 51%.1.5 ↑ ← 45%.1.3	51%.1.3 → ↓ 32%.0.4 41%.1.4 ↑ ← 39%.1.3
		TM 3	61%.2.4 → ↓ 45%.1.6 47%.1.4 ↑ ← 40%.1.3	54%.1.3 → ↓ 34%.1.4 38%.1.3 ↑ ← 35%.1.2
HIGH GROWTH	1,700 → ↓ 600 900 ↑ ← 1,100	TM 1	87%.15.27 → ↓ 81%.4.19 89%.7.22 ↑ ← 62%.2.14	85%.5.9 → ↓ 60%.1.8 70%.2.8 ↑ ← 55%.1.3
		TM 2	89%.7.12 → ↓ 82%.4.20 89%.6.22 ↑ ← 76%.3.8	78%.3.6 → ↓ 60%.1.8 70%.2.8 ↑ ← 65%.2.5
		TM 3	97%.15.27 → ↓ 90%.10.57 77%.3.11 ↑ ← 52%.2.4	85%.5.9 → ↓ 69%.2.11 62%.2.6 ↑ ← 55%.1.3
			KEY:- 74%.3.21 means maximum R.F.C. 74% maximum queue length 3 vehicles, maximum delay per vehicle 21 seconds.	

9. The cost of traffic delays over the scheme life is evaluated for the two options at high growth and low growth using COBA 9. The turning movements are necessarily modified to achieve balanced link flows on a daily basis while continuing to reflect the bias to and from the south. The 63m ICD roundabout is estimated to cost £204,000 and the 70m ICD to cost £276,000, at 1993 prices. (These costs may appear low. They are extra over the basic link costs through the junction). The COBA 9 results are as follows. (All costs are discounted costs in thousands of pounds).

First Scheme Year 1998

Traffic Figures 2010

	Construction Costs	Delay Costs Low	Delay Costs High
63 ICD	144	2628	4455
70 ICD	198	2553	4164
	54	75	291

Therefore Incremental NPV in going from 63m ICD to 70m ICD is:-

Low Growth +21

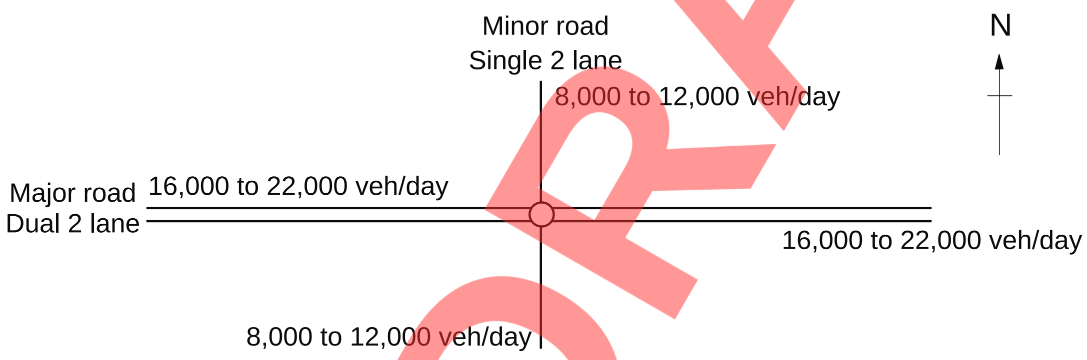
High Growth +237

10. Thus it is likely in this case that the 70m ICD roundabout would be chosen as it shows a much more acceptable maximum RFC (85%) than the smaller design at high growth and a good incremental NPV at high growth, for very modest increase in size. However, if high growth was not likely to occur, or if the scheme involving the larger roundabout involved (say) high statutory undertakers' costs, the 63m ICD roundabout would become more attractive.

Example 2

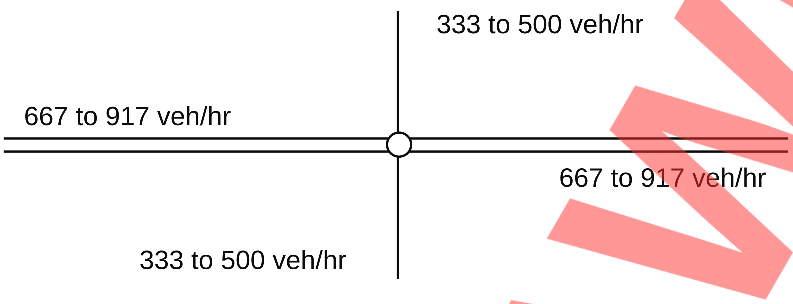
1. It has been decided to construct a roundabout at the junction between a D2AP road and a S2 road on a recreational inter-urban route. Traffic flows vary greatly throughout the year with exceptionally high flows at weekends during the summer months. The surrounding network is also very congested during these summer weekends, but it is considered unrealistic to cater specifically for these exceptional occurrences at this site.

2. The traffic information available from the traffic model is the expected normal high growth and low growth 2-way 24 hour Annual Average Daily Traffic (AADT) flows on each road for the year 2012 (about 13 years after the expected opening date):-



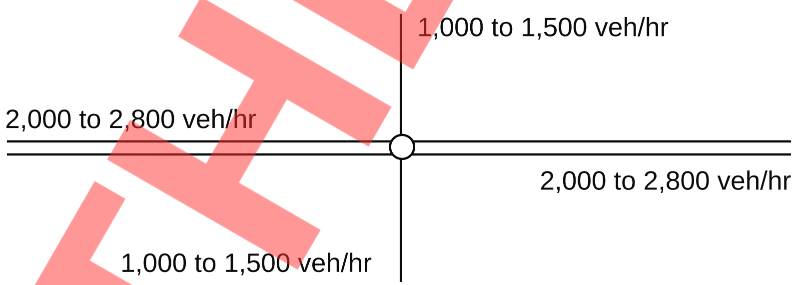
24 hour AADT 2-way flows.

3. From the AADT 2-way flows the Annual Average Hourly Traffic (AAHT) 2-way flows on the approach roads in 2012 are calculated. AAHT = AADT/24, for example 16000/24 = 667, 22000/24 - 917, etc.



AAHT 2-way flows.

4. As there is very high seasonal variation, and it is considered unrealistic to cater specifically for exceptional periods, it has been decided in this particular case to use the estimate of the 200th highest hour in 2012 to obtain the 2-way flows on approach roads in the design peak hour. Thus AAHT is factored by 3.024 (peak to average ratio) (See TAM). For example, 667 x 3.024 = 2017, say 2000; 917 x 3.024 = 2773, say 2800; etc.



Design peak hour 2-way flows.

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5. To avoid repetition the calculation of Reference Flows, and trial layouts are assumed to be identical to those in Example 1.

6. The cost of traffic delays over the scheme life is evaluated for the two options at high growth and low growth using COBA 9. The turning movements are modified to achieve balanced link flows on a daily basis, while continuing to reflect the bias to and from the south. The 63m ICD roundabout is estimated to cost £204,000 and the 70m ICD roundabout to cost £276,000, at 1993 prices. (These costs may appear low. They are extra over the basic link costs through the junction). The COBA 9 results are as follows:- (All discounted costs in thousands of pounds).

First Scheme Year 1998

Traffic Figures 2010

	Construction Costs	Delay Costs	
		Low	**High**
63 ICD	111	1851	3759
70 ICD	150	1794	3081
	39	57	678

Therefore Incremental NPV in going from 63m ICD to 70m ICD is:-

Low Growth +18

High Growth +639

7. Thus it is extremely probable that in this case the 70m ICD roundabout would be chosen, as it has extremely good incremental NPV above low growth for very modest increase in size and an acceptable maximum RFC of 85% at high growth. Also the slight extra land take is less of a problem in rural areas.