GUIDELINES FOR PLANNING AND DESIGN OF ROUNDABOUTS

(First Revision)

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GUIDELINES FOR PLANNING AND DESIGN OF ROUNDABOUTS

The IRC:65 "Recommended Practice for Traffic Rotaries" was first published by Indian Roads Congress in 1976. For the last three decades, India is witnessing massive road development program to improve the mobility and connectivity. New vehicle models have been entered into road system and vulnerable road users are exposed to high speed traffic movement. All these result in road crashes and it is reported that more than 50% of road accidents are junction related accidents. Therefore, a need was felt to revise the IRC:65 for rotary which is a safer junction control where two road of comparable traffic volume is intersecting as well as junction having considerable right turning traffic. Accordingly, the work of revision of IRC:65 was taken up by the Road Safety and Design Committee (H-7) during the tenure 2015-2017 under the Convenorship of Shri Nirmaljit Singh. A subgroup comprising Dr. Sewa Ram (Subgroup Chairman), Dr. Geetam Tiwari, Dr. Manoranjan Parida, Shri Jacob George, Dr. P K Agarwal have developed the draft. The draft prepared by the subgroup was discussed in various meeting of H-7 committee and the document was subsequently approved by H-7 Committee in its meeting held on 18.03.2017 for placing before the HSS Committee.

The Composition of H-7 committee is given below

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The Highways Specifications and Standards Committee approved the draft in its meeting held on 23rd June, 2017. The Member secretary of HSS forwarded extensive comments and the subgroup incorporated all of them. The Executive Committee in its meeting held on 13th July, 2017 considered and approved the same document for placing it before the Council. The Council of IRC in its 212th meeting held at Udaipur on 14th and 15th July, 2017 approved the draft and the final version of the document submitted to IRC for publishing.

1 GENERAL

A roundabout is a specialized form of at-grade intersection where vehicles from the converging arms are forced to move round a central island in one direction in orderly and regimented manner and move/weave out of the roundabout into their desired direction. In conventional roundabout, traffic at entry seek suitable gap in the circulating stream to negotiate the central island. Instead of entering traffic seeking suitable gap with circulating stream, rotary intersection of larger central islands permits weaving maneuvering. The self-regulating form of roundabout is safe because of reduced crossing conflict points and aesthetically pleasing in appearance. When a cross road is converted into a roundabout, the number of conflicts can be reduced from 32 to 8 as illustrated in **Fig. 1.1**, wherein potential right-angle collision will be converted into angular-collision. For these reasons, roundabouts are more safe compared to uncontrolled cross road junction.

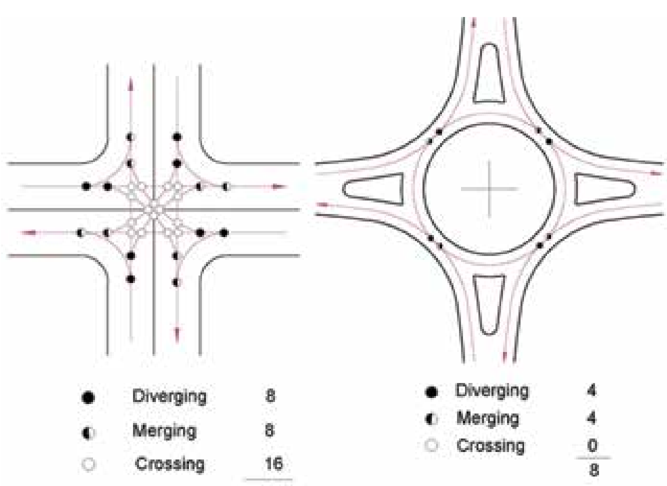


Fig. 1.1 Conflict points in Cross Road Junction Vs. Roundabout

2 DEFINITIONS AND TERMINOLOGIES

The basic definitions and terminologies associated with the roundabouts/rotary and determination of its capacity and level of service are discussed in this section.

2.1 Geometric Parameters

The geometric elements of a typical roundabout/rotary are given in **Fig. 2.1**.

- **Central Island:** It is the raised portions around which the vehicles maneuver to negotiate towards their respective destination. The basic function of the central island is to convert the direct conflict points into angular conflict points and reduce severity of conflict points. It is also meant for providing appropriate turning radius to the vehicle.
- **Circulatory Carriageway:** The clockwise curved path followed by vehicles to move around the central island.
- **Circulatory Carriageway Width:** The width between the outer edge of the kerb face of inscribed diameter and the central island kerb face.
- **Circulating Path Radius:** The minimum radius on the fastest through path around the central island.

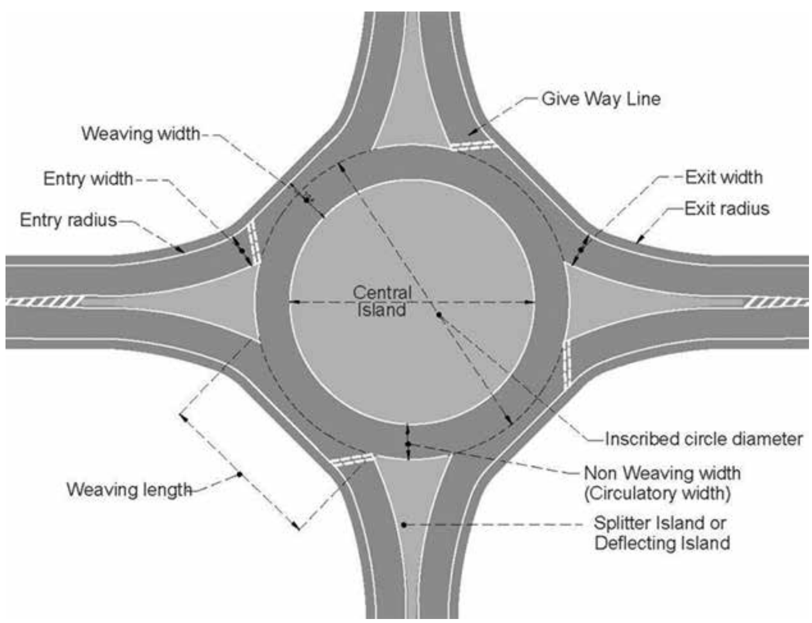


Fig. 2.1 Geometric Elements of Roundabout

- **Entry Radius:** It is radius of curvature provided to entry arm so that vehicle entering from approach road decelerates and enters the roundabout at designated speed.
- **Entry Width:** It is the width of the carriageway at the entry of the roundabout.
- **Exit Angle:** It is the angle by which traffic is deflected from the weaving section towards exit of the roundabout.

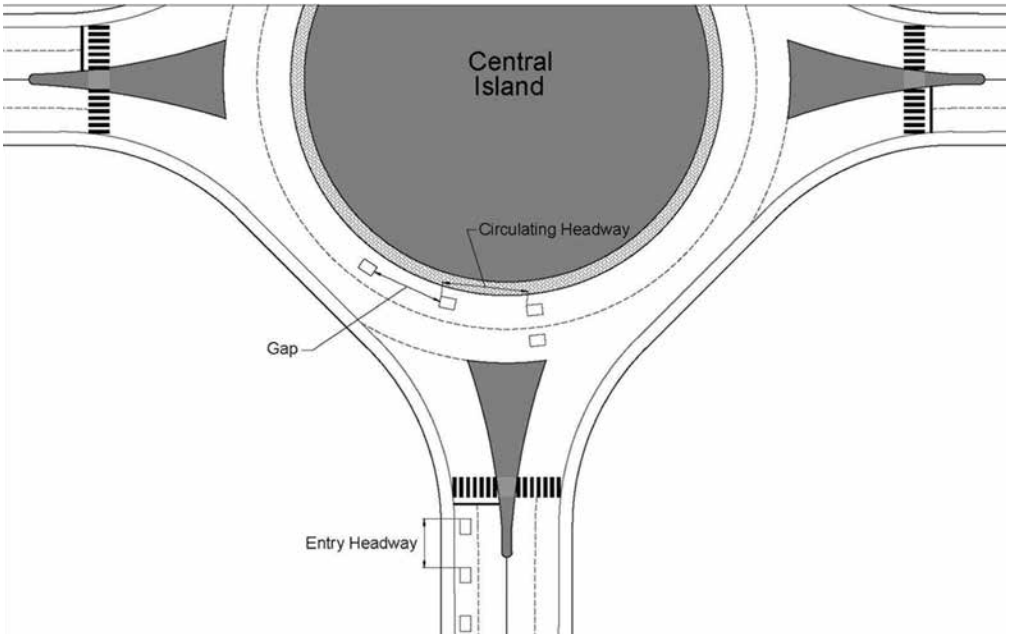
- **Exit Radius:** It is the radius of curvature provided to exit side of the roundabout so that vehicle from roundabout is accelerated to leave the roundabout.
- **Exit Width:** It is the width of the carriageway at the exit of the roundabout.
- **Inscribed Circle Diameter:** The inscribed circle diameter is the basic parameter used to define the size of a roundabout. It is measured between the outer edges of the circulatory path.
- **Non-Weaving Width :** It is the width of the carriageway used by the circulating traffic. It can also be defined as the width of the road from the edge of the central island to the deflecting island as shown in Fig. 2.1.
- **Splitter or Deflecting Island:** It is kerbed island and associated road markings on the carriageway, located between an entry and exit on the same roundabout arm. It is shaped so as to deviate and separate opposing vehicles onto and from the circulatory carriageway of roundabout.
- **Weaving Length:** It is the length of the weaving section in rotary.
- **Weaving Section:** It is the road section used by the traffic wherein either the merging or diverging of traffic takes place within the rotary. It can also be defined as the section where the traffic from both the approach arm and non-weaving enters.
- **Weaving Width:** It is the width of the carriageway of the weaving section in rotary.
- **Giveway Line:** A line of demarcation separating the traffic approaching the roundabout from the traffic in the circulatory carrigeway. The Giveway line is usually defined by dotted edge line pavement marking. Entering vehicles must give way to circulating traffic.

2.2 Flow Parameters

- **Circulating Stream:** The two circulating stream in the roundabout are defined as the near and far major streams, with respect to the entering vehicles or the give way line. For the case of two entry lanes, the inner and outer minor lane are so defined that the outer lane is the one closest to the kerb face.
- **Entry Flow:** The traffic inflow from an entry to a roundabout.
- **Non-Motorized Traffic (NMT) Crossing:** The dedicated roadway section across the vehicular motion for pedestrian and bicycle (preferably separately) near the splitter island.

2.3 Driver Behavior Parameters

- **Classification of Gap Acceptance:** Gap acceptance parameters are affected by geometry of the entry. These parameters are function of the circulating flow and measured in seconds.
- **Critical Gap:** Critical gap is defined as the minimum headway in the circulating flow while an entering vehicle can safely enter a roundabout, assuming all entering drivers are consistent and homogeneous (refer **Fig. 2.2**).



[Source: CRRI (2017) “Indian Highway Capacity Manual (INDO-HCM)”]

Fig. 2.2 Entry & Circulating Headway and Gap

- **Floating Entrance:** If the driver finds a gap and does not have to stop at the entry arm, the vehicle is defined as floating vehicle. It is the first vehicle entering a gap while the succeeding vehicles are known as follow-ups vehicle.
- **Follow-up Time:** Follow-up time is the time span between two queued vehicles entering the circulating stream in the same gap. If more than one vehicle from minor stream uses a gap then the succeeding vehicles are referred to as follow-ups. It can only be measured when there is a queue situation.
- **Gap Acceptance:** All gaps greater than or equal to the critical gap would be accepted.
- **Gap Rejection:** All gaps less than the critical gap would be rejected.
- **Gap:** A gap is the time span between two consecutive circulating vehicles that create conflict with an entering vehicle. The described time span is measured only when the entering driver is at the give way line when the gap begins. (**Fig. 2.2**)
- **Headway:** It is the time between two following vehicles and is measured from the first vehicle’s front bumper to the following vehicle’s front bumper.
- **Lag:** A lag is the time between the arrival of entering vehicle at roundabout entry and the arrival of successive conflicting vehicle in the circulating flow.
- **Static Entrance:** If a vehicle has to stop at the give way line and wait for a sufficient gap before entering the roundabout, it is referred to as static entrance.

2.4 Performance Parameters

- **Delay:** Delay is a parameter used to measure the performance of a roundabout. There are two types of the delays experienced at roundabouts, namely queuing and geometric delay.
- **Entry Capacity:** Entry Capacity at roundabouts is the maximum traffic inflow from an entry to a roundabout when the traffic flow at that entry is sufficient to cause queuing in its approach road.
- **Geometric Delay:** Geometric delay is the delay caused by slowing down the vehicles to stop at the end of queue (if any) after accepting the gap to negotiate, proceeding through the roundabout and then accelerating back to normal operating speed. It excludes the time to wait for an acceptable gap.
- **Level of Service (LoS):** Level of service offers the qualitative traffic flow condition at roundabout, i.e. free flow, stable flow, unstable flow or force flow. At roundabouts, level of service (LOS) is expressed in terms of average delay per vehicle.
- **Queuing Delay:** Queuing delay is the delay caused due to waiting of vehicles to accept a gap in the circulating path.

3 ROUNDABOUTS

Roundabout may be described as an enlarged junction, where all entering vehicles shall give way and find suitable gaps to move around an island in one direction before they move out of the traffic flow into their respective directions radiating from the island. Contrary to the functioning of roundabout, the rotary type of intersection works upon the weaving behavior of entry and circulating traffic. The Inscribed Circle shall be large enough to ensure the weaving in rotary. Based on diameter of Inscribed Circle Diameter (ICD) roundabouts are further categorized to single lane and double lane roundabouts.

3.1 Single Lane Roundabouts

This type of roundabout is characterized as having a single-lane entry at all legs and one circulatory lane. **Fig. 3.1** shows the features of a typical single lane roundabout having a diameter ranging from 28 m to 40 m. The geometric design typically includes raised splitter islands, a non-mountable central-island and pedestrian crossing. The size of the roundabout is largely influenced by the choice of a design vehicle and available Right of Way (RoW). In order to increase the circulating radius of smaller vehicles, a slightly raised circular concrete paved path along the circumference of the central island called Truck Apron can be provided, if required, which would help long vehicles to mount upon them to turn safely.

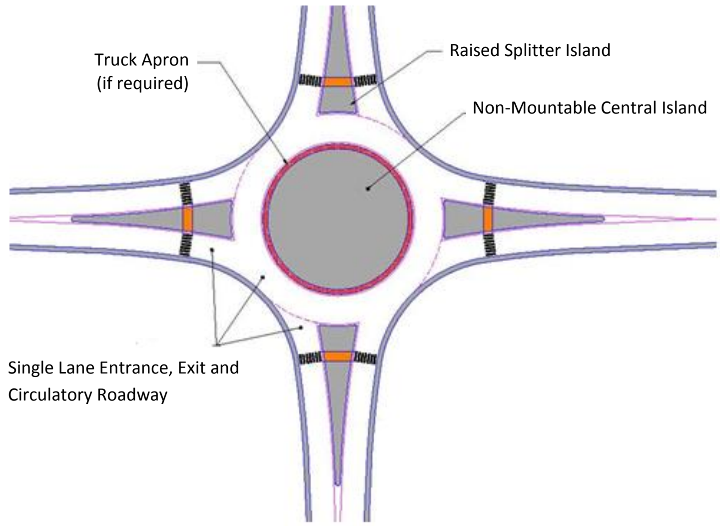


Fig. 3.1 Typical Single Lane Roundabout

3.2 Multilane Roundabouts

Multilane roundabouts are with two or more entry lanes. In some cases, the roundabout may have different number of lanes on one or more approaches (e.g., two lane entry on the major approach and one lane entry on the minor road). They also include roundabouts with entries on one or more approaches that flare from one to two or more lanes. These require wider circulatory roadways to accommodate more than one vehicle travelling side by side. **Fig. 3.2** shows the features of a typical multi-lane roundabout having a diameter ranging from 40 m to 70 m. The speeds at the entry on the circulatory roadway and at the exit are similar or may be slightly higher than those for the single lane roundabouts. The geometric design will include raised splitter islands, a non-traversable central-island, and appropriate entry path deflection.

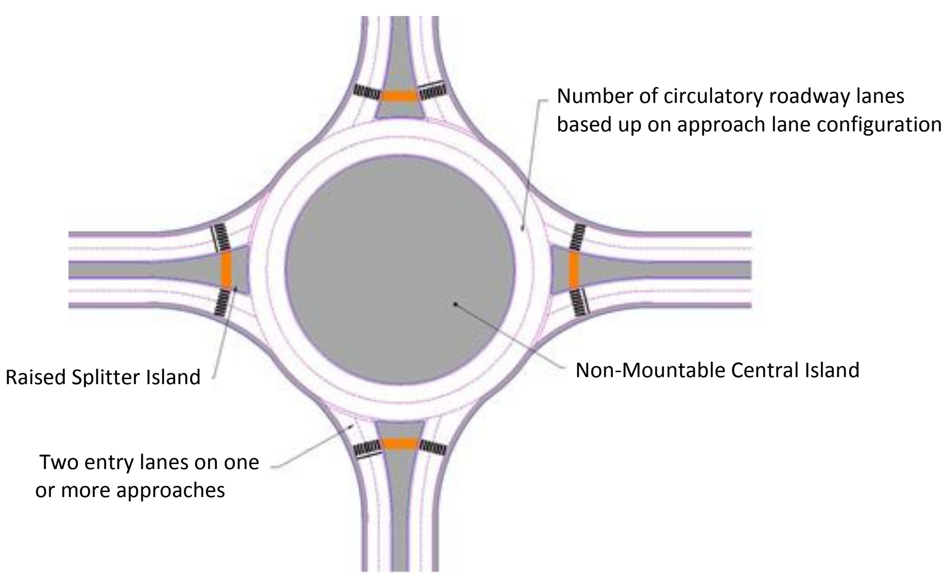


Fig. 3.2 Typical Multilane Roundabout

4 ROTARY INTERSECTION

Roundabout and rotary are two different types of road intersections. Roundabout primarily functions based upon give way behavior by entering traffic giving priority to circulating traffic. A vehicle on approaching the circulatory carriageway, seize the gap in the circulatory movement in order to enter the circular carriageway and always functions based on gap acceptance. Hence compliance to “Priority Rule” is vital for effective function of roundabout. On the other hand, a rotary intersection of large central island works on weaving, wherein a vehicle while entering need not necessarily wait on give way line, rather can merge to circulatory movement and then weave so as to change the lane. Weaving section of rotary has one more lane than non-weaving section. **Table 4.1** presents key differences between roundabout and rotary. The need of gap acceptance in roundabout configuration can be appreciated from **Fig. 4.1** whereas opportunities for weaving in rotary layout are depicted in **Fig. 4.2**.

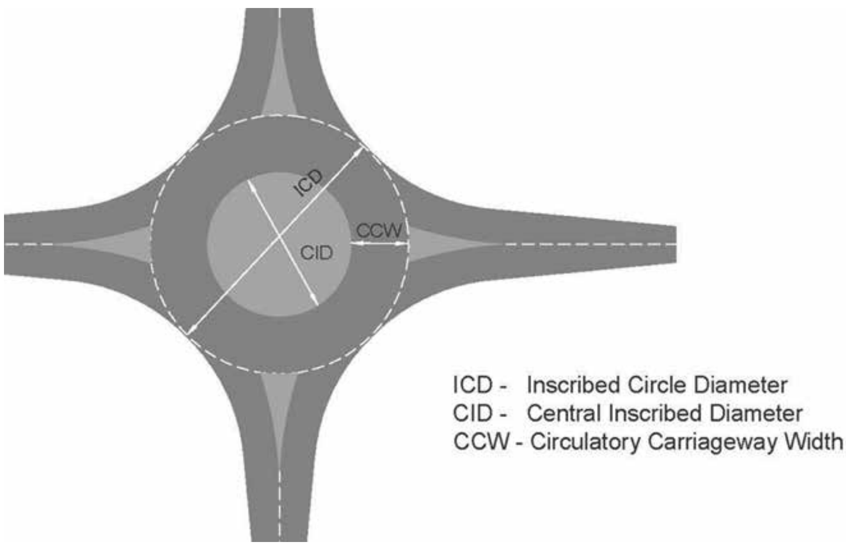


Fig. 4.1 Need of Gap Acceptance in Roundabout Configuration

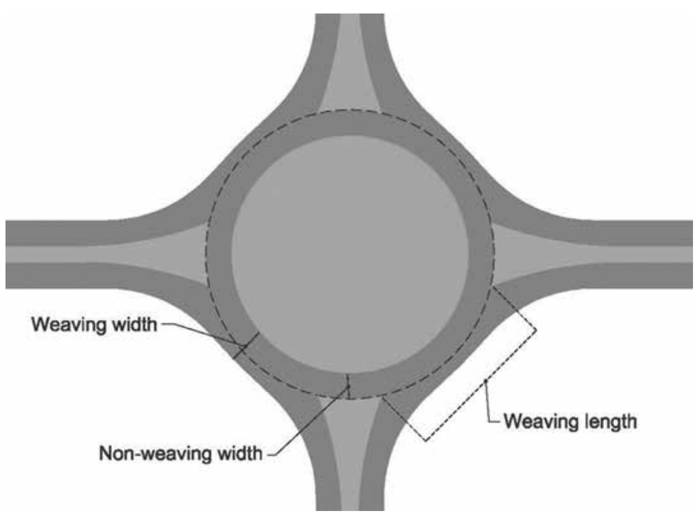


Fig. 4.2 Weaving Opportunities in a Rotary

Table 4.1 Key Differences Between Roundabout and Rotary Intersections

Roundabout	Rotary
1. Smaller in Size	1. Rotary is bigger in size
2. Works on gap acceptance and "priority from rule" is vital for effective function	2. Works on weaving behavior between entering traffic from approach road and circulating stream
3. Maintain relatively low speeds (<40 kmph)	3. Higher speeds allowed (>40 kmph)
4. No pedestrian activity on central island	4. Some large traffic circles allow pedestrian crossing to and from the central island.
5. Large entry angle helps to create entry deflection to control speed through the roundabout	5. Relatively small entry angle
6. Inscribed Circle Diameter (ICD) • Single lane (28-40 m) • Double lane (40-70 m)	6. Inscribed Circle Diameter (ICD) more than 70 m

5 PLANNING CONSIDERATION

5.1 Intersection Hierarchy

Generally the life cycle of a junction from at-grade intersection to grade separated intersection to interchange composed of roundabout and signalized intersections is depicted in **Fig. 5.1**. Moving from unsignalized intersections towards roundabout, channelization of traffic takes place and cross conflict points are converted into angular conflict points as all the vehicles move in clockwise direction. When the entering vehicle at the roundabout are finding difficulty to get suitable gap and delay starts occurring, signalization of roundabout can be a solution. Signalized roundabout is preferred at location where delay occurs during few hours of the day and in remaining maximum time, especially off-peak hour, it can work as conventional roundabout based on priority from right rule. **Fig. 5.1** presents a general hierarchy of intersections and interchanges based upon the capacity handled.

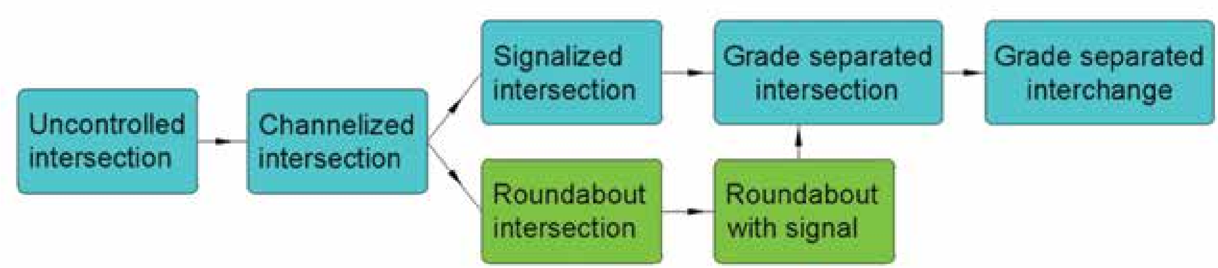


Fig. 5.1 General Hierarchy of Intersections Based Upon Traffic Capacity

It can be observed that signalized intersections and roundabouts have an overlapping region where either of the forms of intersection can be used interchangeably based upon specific site requirements. The planning guide for selection of roundabout as an intersection on various road types is given in **Table 5.1**.

Table 5.1 Roundabouts as an Intersections Type in Various Types of Roads

Intersecting Road with Traffic Volume	Arterial/Rural Highway (3600 PCU/hr)	Sub-Arterial/ Rural Road (2900 PCU/hr)	Collector Road (1800 PCU/hr)	Local Road
Carriageway (1200 PCU/hr)	D	E	E	E
Arterial/Rural Highway (3600 PCU/hr)	B	B	C	C
Sub-Arterial/Rural Road (2900 PCU/hr)	-	B	B	C
Collector Road (1800 PCU/hr)	-	-	A	B
Local Road	-	-	-	A

Notation:

A. Likely to be an appropriate choice

B. May be an appropriate choice

C. Not likely to be an appropriate choice

D. Not appropriate on at-grade

E. Not likely to have a roundabout between carriageway and this road type

Fig. 5.2 exhibits the comparative capacity handled by different types of roundabouts

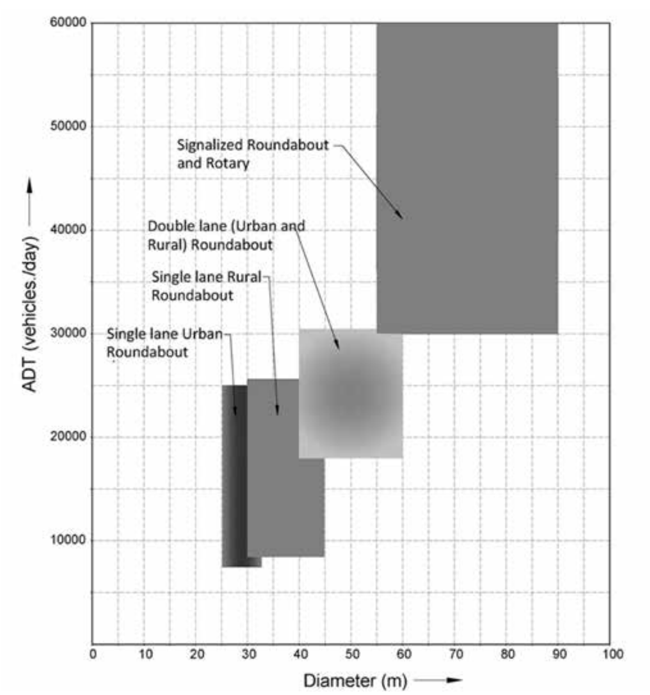


Fig. 5.2 Capacity of different types of Roundabouts

5.2 Passenger Car Unit (PCU) for Roundabout

The PCU of any vehicle is a function of vehicular dimensions and speed of the vehicle only, in case of roundabouts, PCU is also dependent upon turning behavior and conflicts. The PCU value of different modes is dynamic in nature and also depends upon size of roundabout, share of heavy vehicles and overall traffic flow at intersection.

Based on the static and dynamic characteristics, the vehicles in an urban intersection can be classified as two wheelers, three wheelers, big cars, small cars, Light Commercial Vehicles (LCVs), trucks, buses, bicycles etc. The Passenger Car Units for different types of vehicles, based on five important parameters namely traffic flow, headway, conflict angle of vehicles negotiating the roundabout, vehicular speed and composition of traffic have been given in **Table 5.2**.

Table 5.2 Passenger Car Units for Roundabout

<table>
<tr><th>Diameter, D (m)</th><th>Cycle</th><th>Motorized Two Wheeler</th><th>Motorized Three Wheeler</th><th>Small Car</th><th>Big Car</th><th>Light Commercial Vehicle</th><th>Heavy Vehicle</th><th>Cycle Rickshaw</th><th>Hand Cart</th><th>Buffalo Cart</th><th>Horse Cart</th></tr>
<tr><td>20<D≤30</td><td>0.18</td><td rowspan="4">0.32</td><td rowspan="4">0.83</td><td rowspan="4">1.00</td><td rowspan="4">1.40</td><td>1.88</td><td>3.65</td><td>1.12</td><td rowspan="4">2</td><td rowspan="4">4</td><td rowspan="4">3</td></tr>
<tr><td>30<D≤40</td><td>0.21</td><td>1.65</td><td>3.45</td><td>1.31</td></tr>
<tr><td>40<D≤50</td><td>0.25</td><td>1.53</td><td>3.20</td><td>1.56</td></tr>
<tr><td>50<D≤70</td><td>0.28</td><td>1.46</td><td>3.05</td><td>1.74</td></tr>
<tr><td colspan="12">[Source: CRRI (2017) “Indian Highway Capacity Manual (INDO-HCM)”]</td></tr>
</table>

5.3 Site Selection for Roundabouts

Roundabout may be an appropriate choice of traffic management in an at-grade intersection in following situations:

i) At intersections where traffic volumes on the intersecting roads are such that:

a) In case of “Stop” or “Give Way” signs or the “T” junction rule result in inordinate delays for the minor road traffic, roundabouts would decrease delays to minor road traffic, but increase delays to the major road traffic.

b) Traffic signals may result in greater delays than a roundabout. It shall be noted that in many situations roundabouts provide a similar capacity to that of signals, but may operate with lower delays and better safety, particularly in off-peak periods.

ii) At intersections where there are high proportions of right-turning traffic: Unlike most other intersection types, roundabouts can operate efficiently with high volumes of right-turning vehicles.

iii) At rural cross intersections (including those in areas with high desired speeds) which are prone to accidents involving crossing or right turn (versus opposing) traffic. However, if the traffic flow on the lower volume road is less than about 200 vehicles per day, staggered "T" type intersection is preferred.

iv) At intersections of arterial roads in outer urban areas where traffic speeds are high and right turning traffic flows are high. A roundabout could have an advantage over traffic signals in reducing right angle collision type accidents and also in reducing overall delays.

v) At "T", "Y" or cross intersections where the major traffic route turns through a right angle. In these situations, the major movements within the intersection are turning movements.

vi) At locations where traffic growth is expected to be high and where future traffic patterns are uncertain.

vii) At intersections of local roads where it is desirable not to give priority to other road.

viii) At intersections with more than four legs, if one or more legs cannot be closed or relocated or some turns prohibited, roundabouts may provide a convenient and effective solution whereas:

   a) With "Stop" or "Give Way" signs, it is often not practical to define priorities adequately;

   b) Signals may be less efficient due to the large number of phases required resulting in a high percentage of queuing delay.

However, care should be taken in assessing the future traffic volumes and their patterns. It is possible that a site considered appropriate for a roundabout now, may become inappropriate in the future, requiring extensive modifications. Designers should consider the potential to build in flexibility in the design to accommodate possible future changes, particularly when land use alter traffic patterns considerably. Roundabout is not desirable at junction having considerable pedestrian crossing as pedestrian will not get priority to cross a roundabout junction, as traffic ply continuously. Roundabout requires more land than other intersection type of similar capacity, but would have very good safety performance.

6 GEOMETRIC DESIGN

6.1 Central Island and Circulatory Carriageway

The diameter of the roundabout is the diameter of the central island of roundabout/intersection for capacity and LoS estimation.

6.1.1 *Circulating Road width/Width of non-weaving section*

It is the width of the carriageway used by the circulating traffic. It can also be defined as the width of the road from the edge of the central island to the edge of deflecting island. The width of the circulating carriageway depends on several factors, the most important of which are the number of circulating lanes and the radius of vehicle swept paths within the roundabout. Circulating road width is typically between 1.0 and 1.2 times the maximum entry width. Catering all these, Inscribed Circle Diameter and Circulatory Carriageway Width for different category of roundabout assuming 90˚ angle between approach arms and no more than four arms at intersection is given in **Table 6.1**.

Table 6.1 Inscribed Circle Diameter & Circulatory Carriageway Width

Category of Roundabout/Rotaries	Inscribed circle diameter range in m (ICD)	Width of Circulatory Carriageway (CCW), in m
Urban single lane Roundabout	28 – 40	12 m to 8 m
Rural single lane Roundabout	35 – 40	
Urban/Rural double lane Roundabout	40 – 70	1-1.2 times entry width
Multilane Rotary	>70	

6.1.2 In order to ensure the maneuverability of design vehicle for single lane roundabout of Inscribed Circle Diameter (ICD) upto 40 m, a combination as given in **Table 6.2** shall be followed between Inscribed Circle Diameter and Central Island Diameter. It is desirable to provide a Truck Apron for single lane roundabout having smaller Central Island Diameters, which would ensure adequate deflection for light vehicles.

Table 6.2 Inscribed Circle Diameter and Central Island Diameter for Single Lane Roundabout

Inscribed Circle Diameter (m)	Central Island Diameter (m)	Width of Circulatory Carriageway(m)
28	4**	12
30	8	11
32	12	10
36	18	9
40	24	8

[Source: Design Manual for Roads & Bridges, UK, TD 16/07, 2007]

** Desirable to provide a Truck Apron to ensure the deflection of light vehicles

6.2 Positioning of Central Island

6.2.1 Ideally the Central Island should be located in such a way that center lines of approach road passes through the center of Inscribed Circle. The size and position of Central Island shall be such that all approach vehicles will have to be deflected even that approaching from extreme left lane on the approach road.

6.2.2 It is desirable to equally space the angle between entry arms of roundabout.

6.3 Entry and Exit Design

The roundabout entry design depends upon various variables like entry width, entry flaring and entry angle.

6.3.1 *Entry Width*

The entry width is the width of the carriageway at the point of entry. It is measured from the point "A" at the right hand end of the give way line along the normal to the nearside kerb as given in **Fig. 6.1.**

6.3.2 One lane width at the give way line (measured along the normal to the nearside kerb, as for entry width) must be not less than 3 m or more than 4.5 m, with the 4.5 m value appropriate at single lane entries and values of 3 to 3.5 m appropriate at multilane entries.

6.3.3 *Exit Width*

The exit width is the width of the carriageway on the exit and is measured in a similar manner to the entry width. It is the distance between the nearside kerb and the exit median (or the edge of any splitter island or central reserve) where it intersects with the outer edge of the circulatory carriageway.

6.3.4 The downstream link in a undivided two way road with a long splitter island of a normal roundabout should be between 7 m and 7.5 m. The exit should taper down to a minimum of 6 m allowing traffic to pass a broken down vehicle. If the link is an all-purpose two-lane dual carriageway, the exit width should be between 10 m and 11 m and the exit should taper down to two lanes wide. The width should be reduced in such a way as to avoid exiting vehicles encroaching onto the opposing lane at the end of the splitter island. Normally the width would reduce at a taper of 1:15 to 1:20. Where the exit is on an up gradient, the exit width may be maintained for a short distance before tapering in.

6.3.5 The carriageway width at entrance and exit of a roundabout is governed by the amount of traffic entering and leaving the roundabout. While deciding upon the width, the possible growth of traffic in the design period should be considered. It is recommended that the minimum width of carriageway be at least 5 m with necessary extra widening to account for the curvature of the road. **Table 6.3** gives the value of the width of carriageway at entry inclusive of widening needed on account of curvature.

6.3.6 *Radius of Entry Curve*

It is measured as the minimum radius of curvature of the curve as shown in **Fig. 6.1**. The provision of an appropriate radius on the entry curve encourages drivers to slow down before reaching the roundabout. Radius of curve at the entry is critical for design speed, amount of superelevation and the coefficient of friction. The values of coefficient of friction for roundabout approaches shall be higher than for other locations. Based on overall considerations, **Table 6.3** gives guidance for the selection of radii of curves at entry.

6.3.7 *Radius of Exit Curve*

It is measured as the minimum radius of curvature of the curve as shown in **Fig. 6.1**. Values for the exit kerb radius should exceed the largest entry radius. In areas where there are no pedestrians, the exit from a roundabout should be as easy to negotiate as practicable. After having been slowed down by the entry and circulating curves, vehicles should be able to accelerate on the exit. Therefore, the radius of the exit curve should generally be greater than the circulating radius. In areas where there are pedestrians, the exit speed should be minimized. The best solution to minimize the exit speed is to provide radii similar to those at entrances as given in **Table 6.3.**

Table 6.3 Radius of Entry & Exit Curve & Width

Intersecting Road	Number of Approach Lane(s)	Roundabout Design Speed (kmph)	Radius of Entry and Exit Curve (m)	Width of carriageway at entry and exit (m)
2 lane Undivided Road	One	20-30	20-40	6.5
4 lane Divided Road	Two	25-40	30-75	8.0
6 lane Divided Road	Three	30-45	50-100	13.0

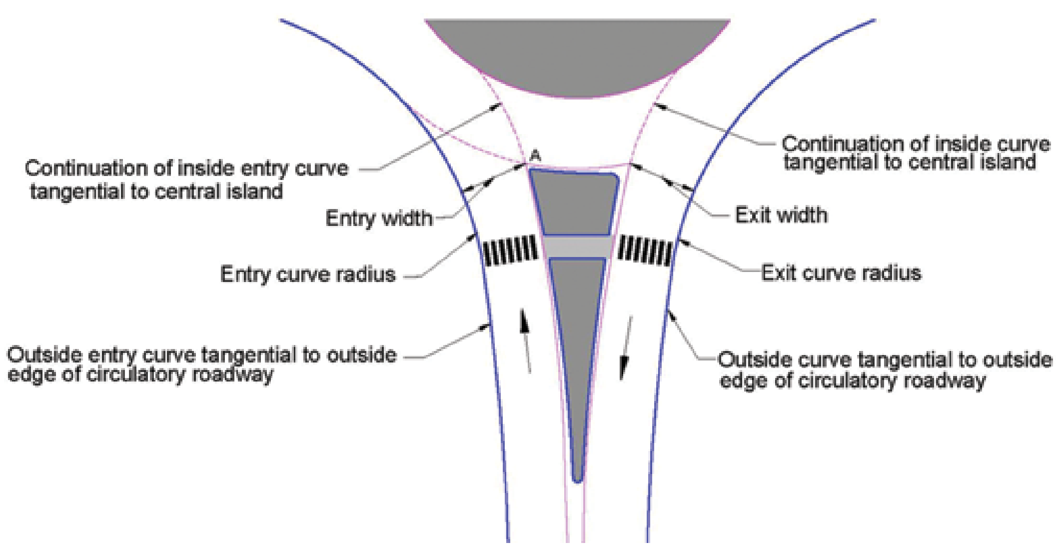


Fig. 6.1 Radius of Entry and Exit Curve

6.4 Splitter/Channelizing Islands

6.4.1 Splitter and channelizing island are provided on each arm of roundabout to direct and separate opposing traffic movements onto and from a roundabout. Splitter island shall be of physical islands where there is sufficient space to accommodate kerbed island. **Fig. 6.2** demonstrates the use of splitter islands on roundabout, which would prevent wrong right turning.

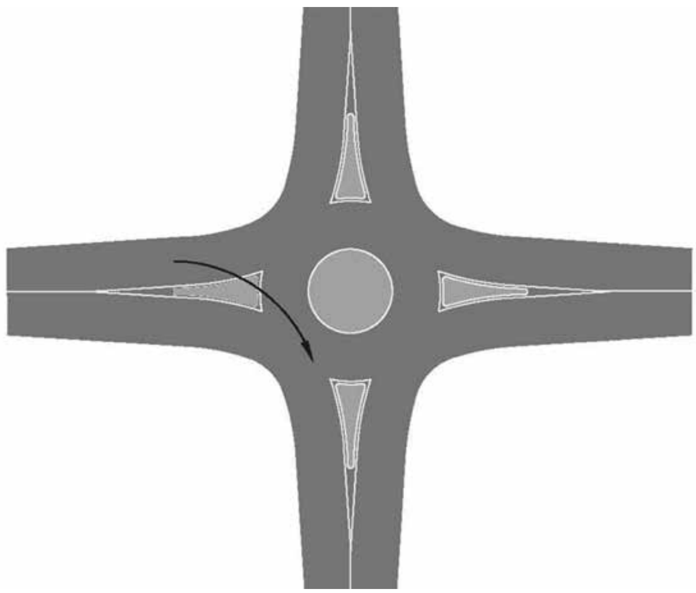


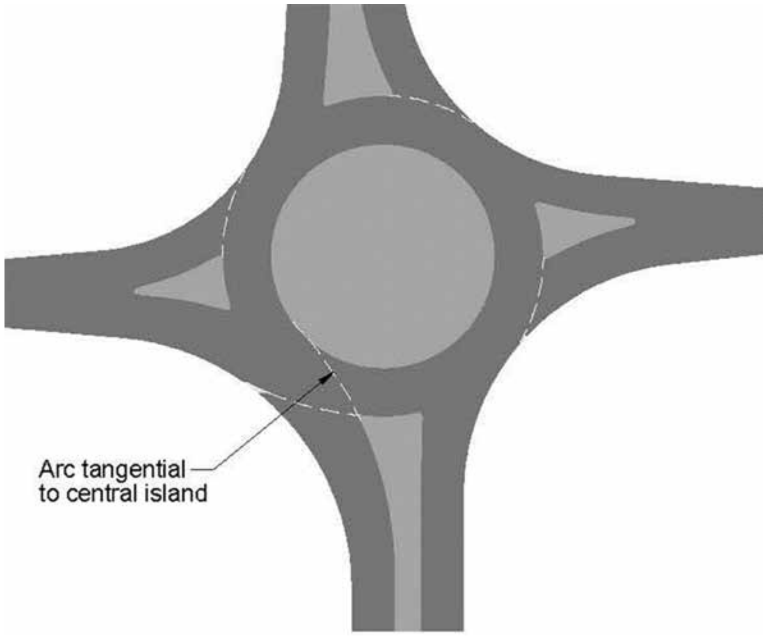
Fig. 6.2 Use of Splitter Islands to Discourage Hazardous Wrong Way Movements

6.4.2 Kerbed splitter islands should be provided on all approaches as they would provide shelter for pedestrians, assist in controlling entry speed, and guide traffic onto the roundabout and also deter right-turners from taking dangerous “wrong way” short cut movements through the roundabout.

6.4.3 On urban arterial road roundabouts, the kerbed splitter island should be of sufficient size to shelter a pedestrian (at least 2.4 m wide) and be highly visible to approaching traffic. A minimum area of 8 m^2 to 10 m^2 should be provided on any arterial road approach. On roundabout approaches from local roads, the general minimum area of kerbed splitter island is 5 m^2 to 8 m^2. In extremely constrained cases, it is preferable to provide a kerbed splitter island smaller than the general minimum rather than provide no island at all.

6.4.4 In high speed areas the splitter island should also be relatively long to give early warning to drivers that they are approaching an intersection and must slow down. Preferably the splitter island and its approach pavement markings should extend back to a point where drivers would be expected to start to reduce their speed.

6.4.5 The kerb line of splitter island or median in case of a divided carriageway should lie on arc which when projected forward meets the central island tangentially as shown in **Fig. 6.3**



[Source: Design Manual for Roads & Bridges, UK, TD 16/07, 2007]

Fig. 6.3 Arc Projecting Forward from the Splitter Island and Tangential to Central Island

6.4.6 The details of geometric design of splitter island are given in **Fig. 6.4** and **Fig. 6.5**

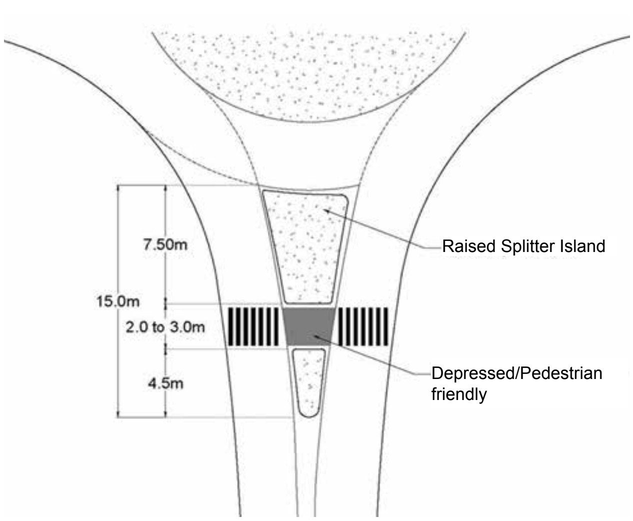


Fig. 6.4 Minimum Size of Splitter Island

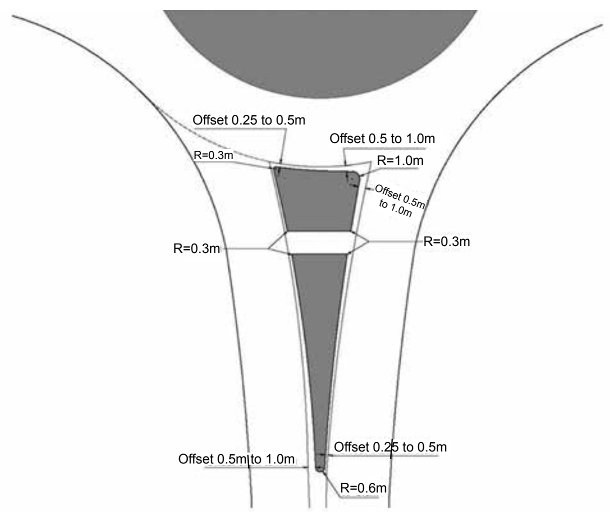
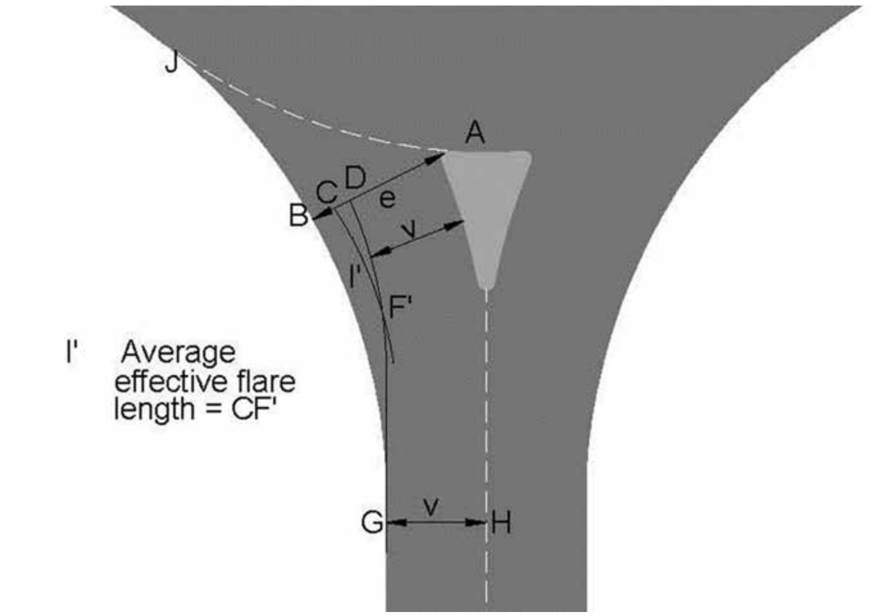


Fig. 6.5 Minimum Splitter Island Nose Radii and Offset

6.5 Entry Flaring

Entry flaring is localized widening at the point of entry. Normal Roundabouts usually have flared entries with the addition of one or two lanes at the give way line to increase capacity.

6.5.1 The average effective flare length, l', is the average length over which the entry widens. It is the length of the curve CF', shown in **Fig. 6.6**



[Source: Design Manual for Roads & Bridges, UK, TD 16/07, 2007]

Fig. 6.6 Average Effective Flare Length

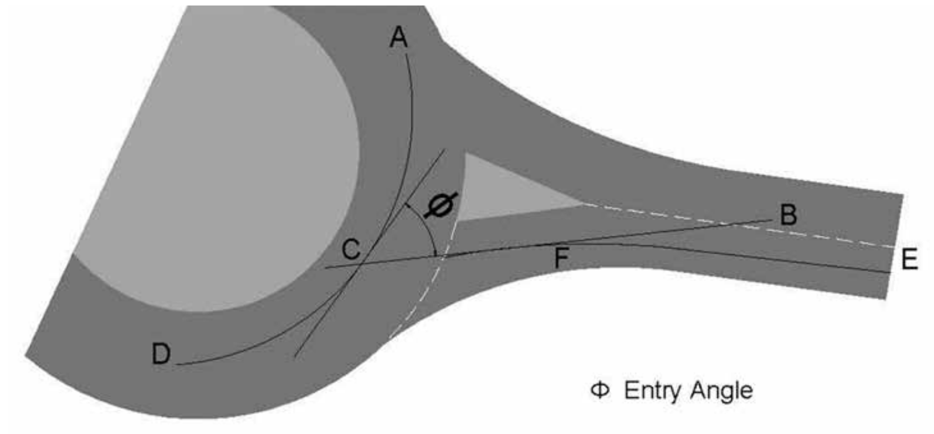
6.5.2 Procedure to determine the average effective flare length, l’: As shown in **Fig. 6.6**, construct curve GD parallel to the median HA (centre line or edge of central reserve or splitter island) and distance v from it; then construct curve CF’ parallel to curve BG (the nearside kerb) and at a constant distance of ½ BD from it, with F’ the point where CF’ intersects line DG. The length of curve CF’ is the average effective flare length l’. The total length of the entry widening (BG) will be about twice the average effective flare length.

6.5.3 A minimum flare length of about 25 m is desirable, but capacity will be the determining factor. Effective flare lengths greater than 25 m may improve the geometric layout but have little effect in increasing capacity. If the effective flare length exceeds 100 m, the design becomes one of link widening

6.6 Entry Angle

The entry angle, serves as a geometric proxy for the conflict angle between entering and circulating traffic streams. There are two different methods for its measurement, depending on the size of the roundabout.

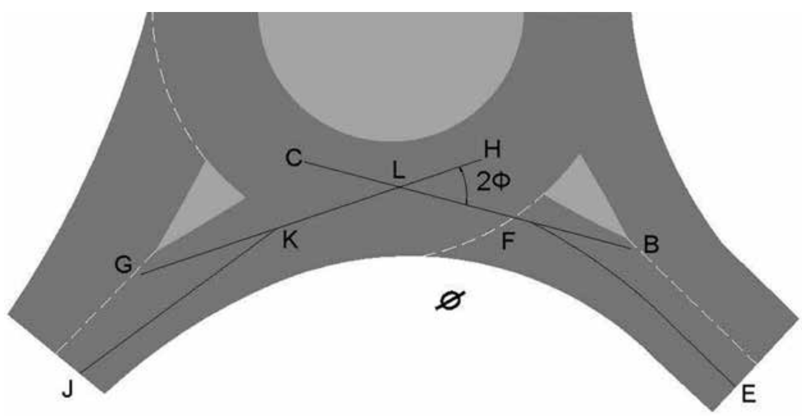
6.6.1 Procedure to determine to determine entry angle: For large roundabout like that given in **Fig. 6.7** construct the curve EF as the locus of the mid- point between the nearside kerb and the median line (or the edge of any splitter island or central reserve); then construct BC as the tangent to EF at the give way line; construct the curve AD as the locus of the mid-point of (the used section of) the circulatory carriageway (a proxy for the average direction of travel for traffic circulating past the arm); the entry angle, Angle ACB is the entry angle



[Source: Design Manual for Roads & Bridges, UK, TD 16/07, 2007]

Fig. 6.7 Entry Angle at a Larger Roundabout

6.6.2 For Single Lane Roundabouts, the entry angle is measured as shown in **Fig. 6.8**. This construction is used when there is insufficient separation between entry and adjacent exit to be able to define the path of the circulating vehicle clearly. In this case, circulating traffic which leaves at the following exit will be influenced by the angle at which that arm joins the roundabout. The angle between the projected entry and exit paths is measured and then halved to find entry angle.



[Source: Design Manual for Roads & Bridges, UK, TD 16/07, 2007]

Fig. 6.8 Entry Angle at a Smaller Roundabout

6.6.3 The entry angle should lie between 20 and 60. Entry angles should be larger than exit angle.

6.7 Weaving Width in Rotary

The width of the weaving section of the rotary should be one traffic lane (3.5 m) wider than the mean entry width thereto as shown in **Fig. 6.9**

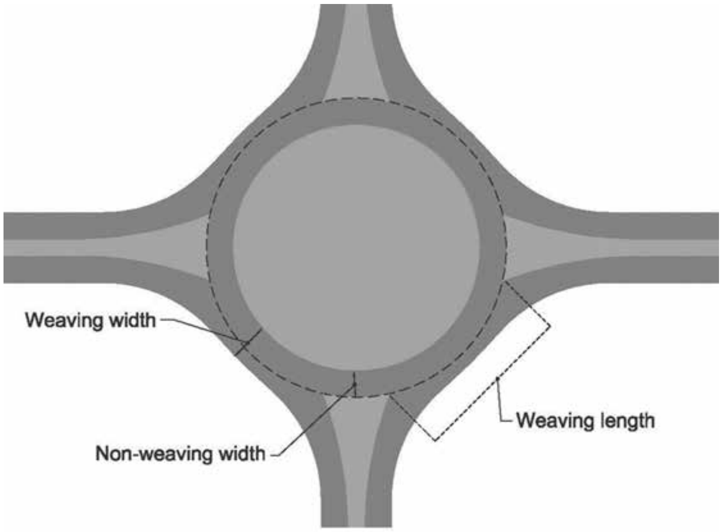
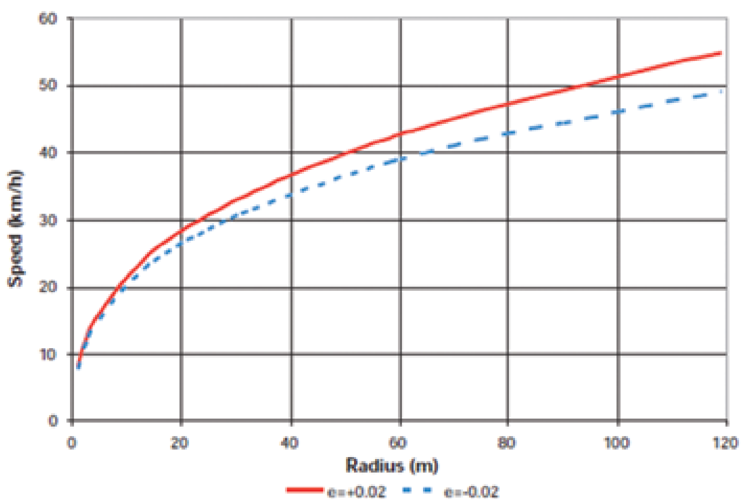


Fig. 6.9 Weaving Width in Rotary

6.8 Design Speed

6.8.1 Roundabouts operate at speeds lower than that of the network preceding and succeeding it as it requires give way behavior and gap acceptance. Generally, vehicles are expected not to run more than 30 km/h around urban roundabouts. Rural roundabouts may have higher operating speeds but still the speed of vehicles at roundabouts is expected to be lesser than that of mid-block sections.

6.8.2 Based upon sight distance and specific turning radius, the design speeds can be reduced but excessively reduced speeds may result into increased delay at roundabouts and in turn deteriorated level of service. **Fig. 6.10** presents the typical relationship between operating speeds at roundabout and radius of Central Island.



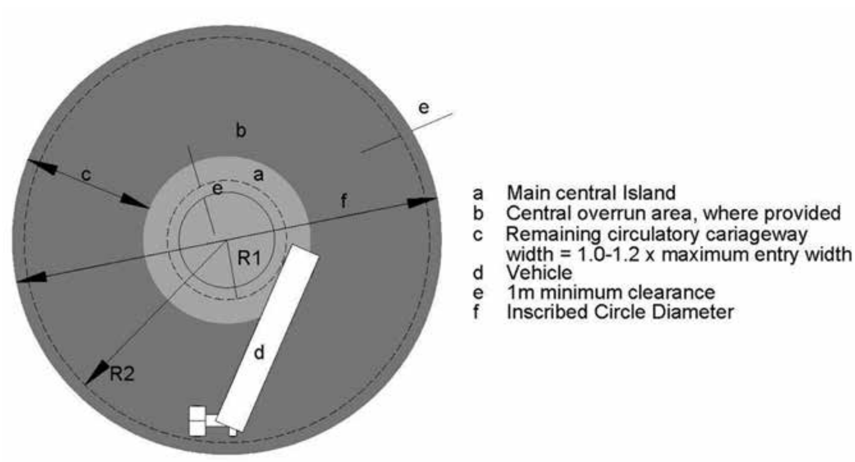
e stands for super-elevation

Fig. 6.10 Relationship between Radius of Central Island and Operating Speeds at Roundabout

6.9 Design Vehicle

6.9.1 The design vehicle and consequently the swept path requirements may be different for various paths through the roundabout. Because travel through roundabouts involves complex reverse-turn movements, particular care is needed in the use of simple turning path templates to achieve a satisfactory layout. **Fig. 6.11** and **Table 6.4** shows turning width required for a Single Lane Roundabout for ICD diameter upto 36 m.

6.9.2 A roundabout of Inscribed Circle Diameter from 28 m to 36 m can facilitate minimum turning radii requirement including U-turn for Design Vehicle upto Large Semi trailer Wheel Base (WB)-15 of 2.58 m overall width, 16.7 m overall length and 13.7 m minimum turning radius.



[Source: Design Manual for Roads & Bridges, UK, TD 16/07, 2007]

Fig. 6.11 Turning widths required for Normal Roundabout

Table 6.4 Turning Radii required for a Normal Roundabout

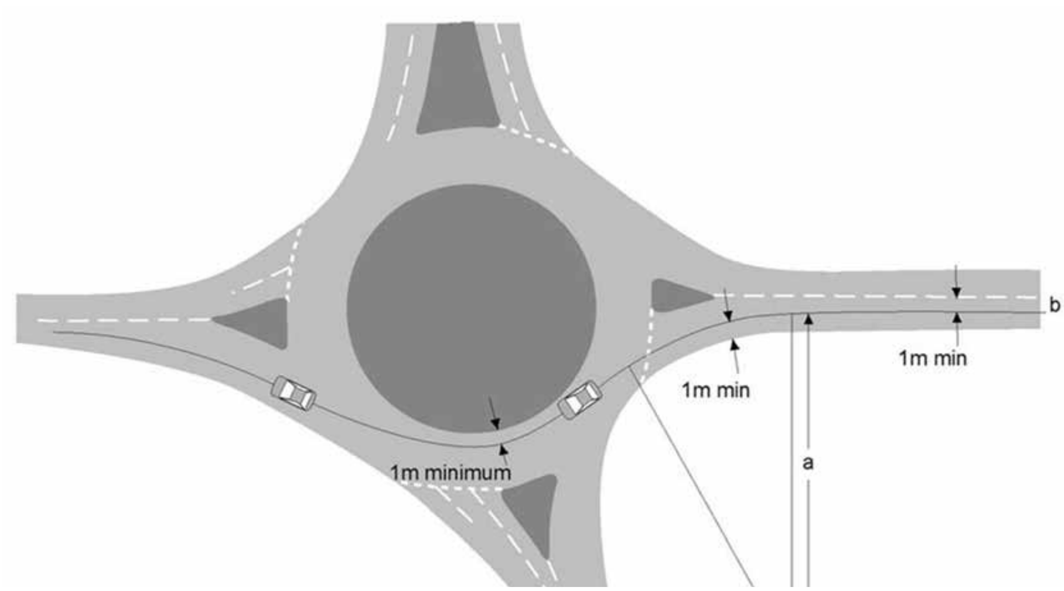
Central Island Diameter (m)	R1 (m)	R2 (m)	Minimum ICD (m)
4.0	3.0	13.0	28.0
6.0	4.0	13.4	28.8
8.0	5.0	13.9	29.8
10.0	6.0	14.4	30.8
12.0	7.0	15.0	32.0
14.0	8.0	15.6	33.2
16.0	9.0	16.3	34.6
18.0	10.0	17.0	36.0
[Source: Design Manual for Roads & Bridges, UK, TD 16/07, 2007]			

6.9.3 A roundabout of Inscribed Circle Diameter above 36 m can cater all movement including U-turn of even Design Vehicle of Large Semi tailor (WB-18) of 2.58 m overall width, 19.7 m overall length and 18.2 m minimum turning radius.

6.10 Path Alignment

6.10.1 Drivers select their paths to obtain the largest possible radii (i.e. select their path to maximize their speed, as depicted in **Fig. 6.12**. It has been found that drivers typically travel to maintain the following distances between the edge of their vehicles and particular geometric features:

- 0.5 m from a road center-line.
- 0.5 m from the face of concrete kerb and channeling,
- 0 m from a painted edge line or chevron.



[Source: Design Manual for Roads & Bridges, UK, TD 16/07, 2007]

Fig. 6.12 Determination of Entry Path Radius for Ahead Movement at a 4-arm Roundabout

Assuming an average vehicle is 2 m wide, the following distances from the center line of the vehicle to the above geometric features result:

- 1.5 m from a road center-line,
- 1.5 m from concrete kerb and
- 1 m from a painted edge line or chevron.

6.11 Sight Distance

Sight distance is essentially the sight “triangle” (which may be on a curve) needed for a driver who does not have the right of way to perceive and react to a conflicting pedestrian, vehicle or bicyclist. Roundabouts have an advantage over standard intersections in that there are fewer conflicts to check for sight distance requirements. The minimum required sight distance is actually preferred in order to keep speeds low at the roundabout. Three sight distance principles must be applied to the combination of vertical and horizontal geometrics at roundabouts. These criteria affect the positioning of signs, landscaping, poles and other roadside furniture.

6.11.1 The alignment on the approach should be such that the driver has a good view of both the splitter island, the central island and desirably the circulating carriageway. Adequate Approach Sight Distance (ASD) should be provided to the give way lines and pedestrian crossing as shown in **Fig. 6.13** for the approach speed given in **Table 6.5**.

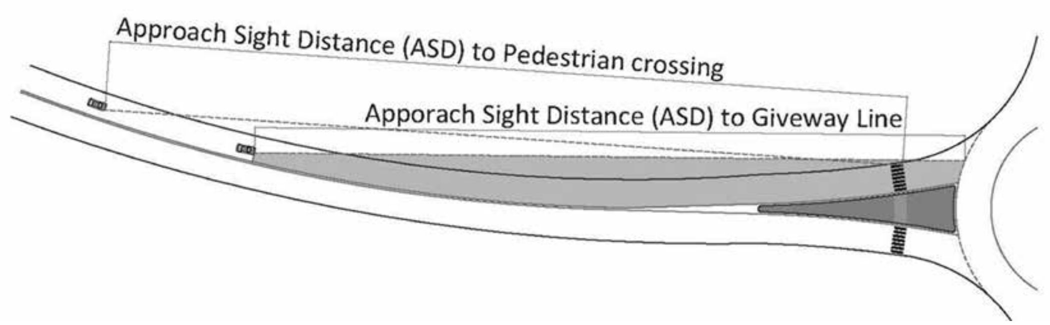


Fig. 6.13 Measurement of Approach Sight Distance on Curved Approach

Table 6.5 Required minimum Approach Sight Distance Criteria

*Speed (km/h)	** Approach Sight Distance (m)
40	30
50	40
60	60
70	70
80	105
90	130
100	160
110	190
120	230
*On the geometric element prior to the entry curve. **Measured from a passenger car eye height of 1.15 m to an object cut-off height of 0 m.	

6.11.2 *Other Visibility Considerations*

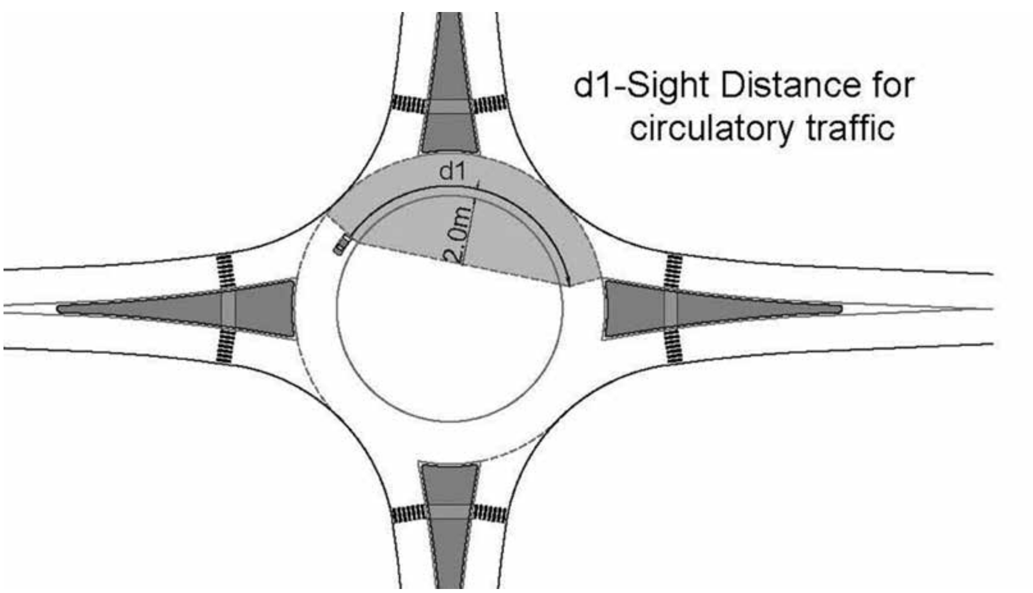
A driver, stationary at the stopping line, should have a clear line of sight (using a passenger car eye height of 1.15 m) to traffic on any previous approach (an object height of 1.15 m passenger car eye height). The desirable minimum length of this line of sight is based on the distance travelled in 4 seconds (observation time plus reaction time) at the 85th percentile speed plus the stopping distance (measured along vehicle paths from previous approaches). The absolute minimum length of this line of sight is based on the distance travelled in 2.5 seconds (observation time plus reaction time) at the 85th percentile speed plus the stopping distance. Desired and absolute minimum sight distance at 85th percentile speed is as given in **Table 6.6**.

Table 6.6 Absolute and desired minimum sight distance at 85th percentile speed

85th Percentile Speed (km/h)	Criterion for Minimum Sight Distance in m	
	Absolute Minimum – 2.5s Observation & Reaction Time	Desirable Minimum – 4s Observation & Reaction Time
20	17	25
30	28	40
40	40	57
50	54	74
60	71	96
70	91	121
80	114	147

[Source: Road Planning & Design Manual, Queensland]

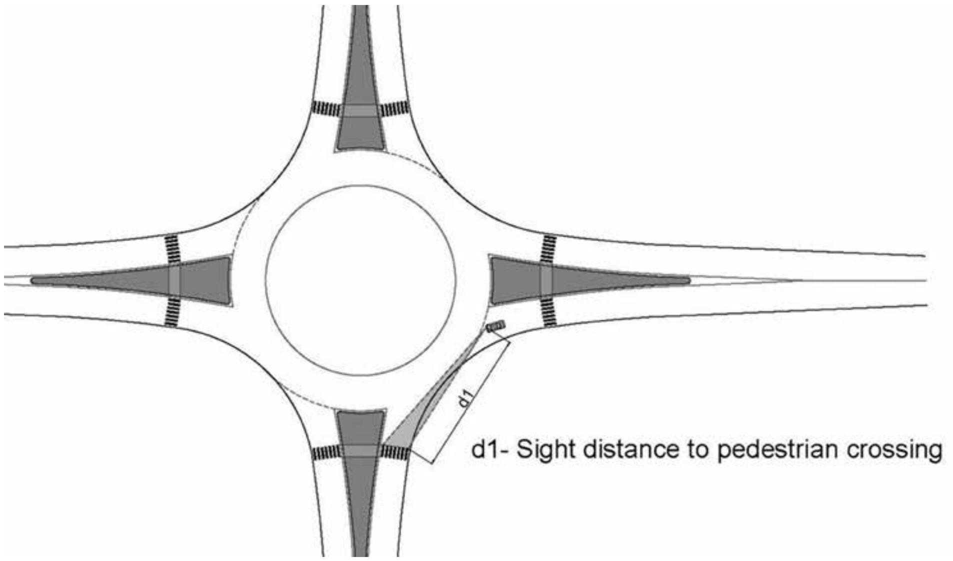
6.11.3 Traffic plying within circulatory roadway should have sight distance as given in **Fig. 6.14.**



[Source: Design Manual for Roads & Bridges, UK, TD 16/07, 2007]

Fig. 6.14 Circulatory Visibility Requirement

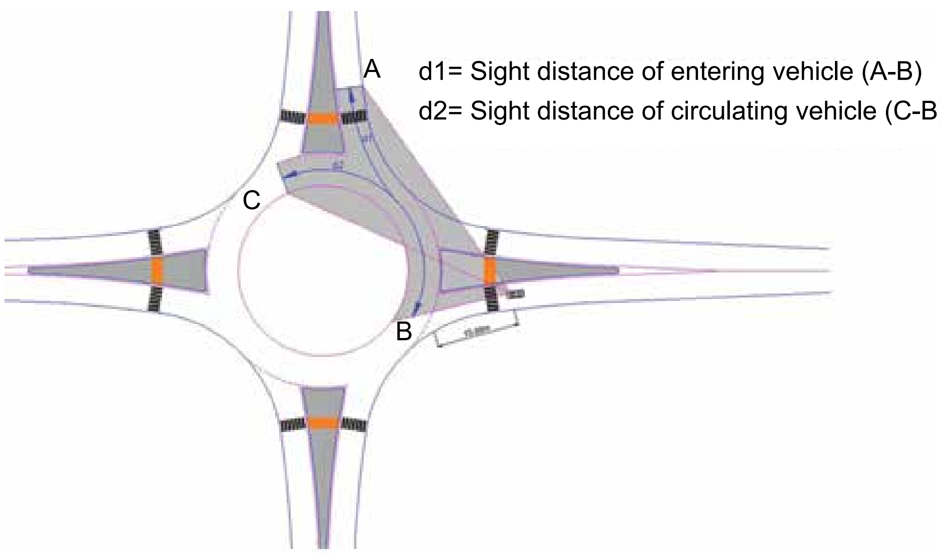
6.11.4 Traffic approaching a pedestrian crossing should have sight distance as given in **Fig. 6.15.**



[Source: Design Manual for Roads & Bridges, UK, TD 16/07, 2007]

Fig. 6.15 Measurement of Visibility required at Entry to Pedestrian Crossing

6.11.5 Intersection sight distance as given in **Fig. 6.16** shall be ensured for drivers to see the conflicting vehicles



[Source: Design Manual for Roads & Bridges, UK, TD 16/07, 2007]

Fig. 6.16 Measurement of Intersection Sight Distance

6.11.6 It is preferable to position a roundabout in a sag rather on a crest. It is important to avoid placing a roundabout just over a crest where the layout is obscured from the view of approaching drivers.

6.11.7 At grade separated roundabouts, particularly where there may be a structure (e.g. pier) in the central island which might obstruct a driver's visibility, care must be taken to ensure that the sight distance requirements are met. Any safety barriers used to protect piers, structures, embankments etc. may also interfere with visibility and must be located to avoid this interference

6.12 Grade of Intersecting Road

A roundabout should preferably be located on level ground. It may be sited to lie on a plane which is inclined to the horizontal at not more than 1 in 50. It is, however, not desirable that a roundabout be located in two planes having different inclinations to the horizontal. A roundabout may, with advantages be located on a summit. Such locations assist deceleration while approaching and acceleration while leaving the roundabout.

For roundabouts in valleys always provide a full view to the approaching vehicles, but are likely to induce greater approaching speeds and have drainage difficulties.

6.13 Camber and Super-elevation

6.13.1 For Single Lane Roundabout upto 40 m ICD, uni directional camber of the order 0.5% to 1% can be provided to drain the surface runoff away from central island as shown in **Fig. 6.17**

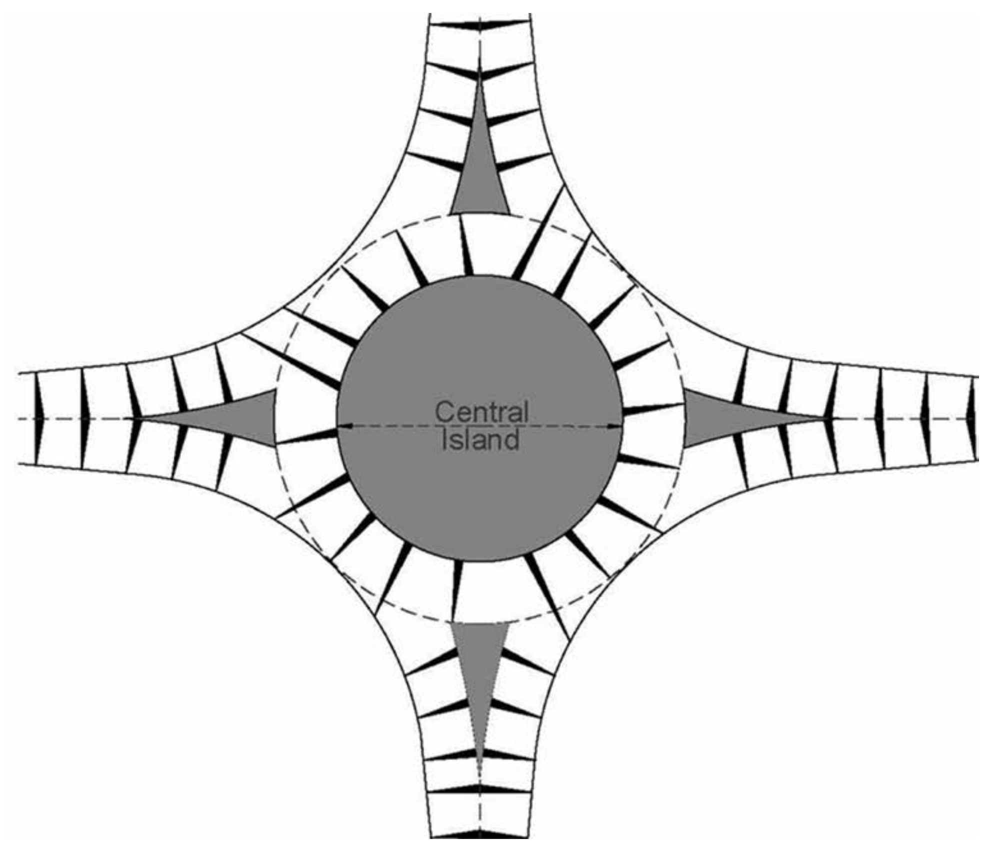


Fig. 6.17 Camber in Single Lane Roundabout

6.13.2 Camber for Rotary and Bigger Roundabout

For all roundabout with ICD above 40 m and rotary, since the curvature is opposite to that of entry and exit, vehicles, especially heavy buses and trucks, experience difficulty in changing over from one cross-slope to another in the opposite direction. It is, therefore, recommended that the algebraic difference in the cross-slopes be limited to about 5%. The super-elevation should be limited to the least amount consistent with design speed. The crown-line which is the line of meeting of opposite cross-slopes should, as far as possible, be located such that vehicles cross it while travelling along the common tangent to the reverse curve. Channelizing islands should be situated on the peak with the road surfaces sloping away from them to all sides. Whenever possible, the cross-slope at an entrance should be carried around on the outer edge of the roundabout to the adjacent exit, altering the slope slightly to suit the curvature in the rotary and the exit. A typical disposition of cross-slopes in a roundabout is indicated in **Fig. 6.18**.

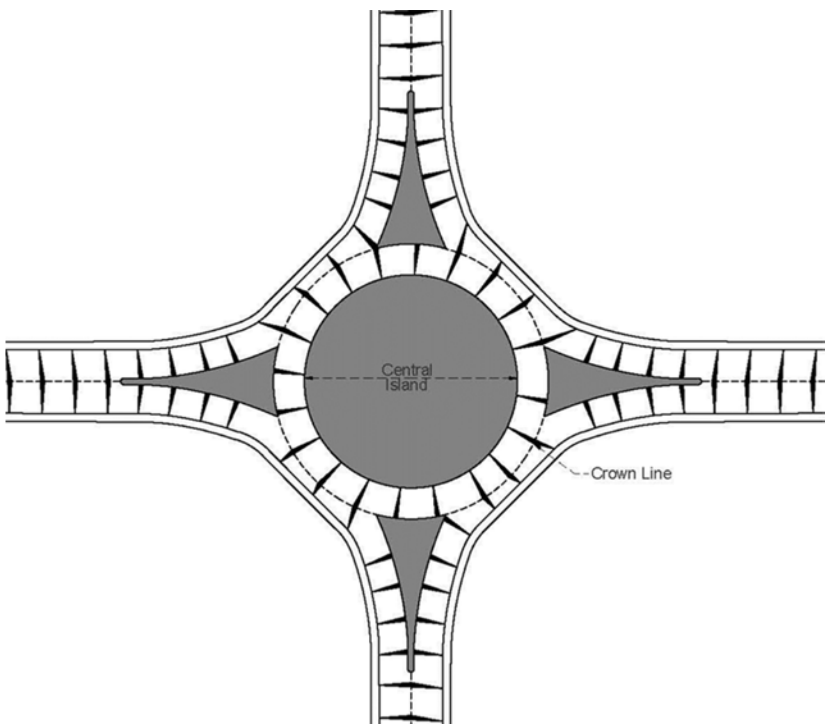


Fig. 6.18 Camber and superelevation in Two lane Roundabout and in Rotary

6.14 Drainage

Drainage at roundabout is a crucial part of planning and design. The reasons to provide a sound and long-lasting drainage system are:

- To prevent flooding of the road and ponding on the road surface.
- To protect the bearing capacity of the pavement and the sub grade material.
- To avoid the erosion of side slopes.

For more details on drainage, reference may be made to IRC:SP:42 “Guidelines of Road Drainage” and IRC:SP:50 “Guidelines on Urban Drainage”.

6.15 Kerbs

The kerbs for channelizing and central islands should be either vertical kerbs or mountable kerbs. The height of the kerb of the central island shall not be more than 225 mm and shall be non-mountable type. Utmost care shall be given that visibility shall not be obscured.

The kerbs at the outer edges of rotary and at the approach roads should preferably be of the vertical type. The approaches should be provided with kerbs up to a minimum distance of 30 m from the point where the flaring of the approach starts.

6.16 Road Signs and Pavement Markings

Road signs and pavement marking shall be placed at convenient and suitable locations to safeguard and guide to uninterrupted traffic. The Lane marking and signing may be provided as per the guidelines given in IRC 35 "Code of Practice for Road Markings" and IRC:67 "Code of Practice for Road Signs" respectively. **Fig. 6.19** and **Fig. 6.20** show a typical sign and marking plan for roundabout and rotary layout.

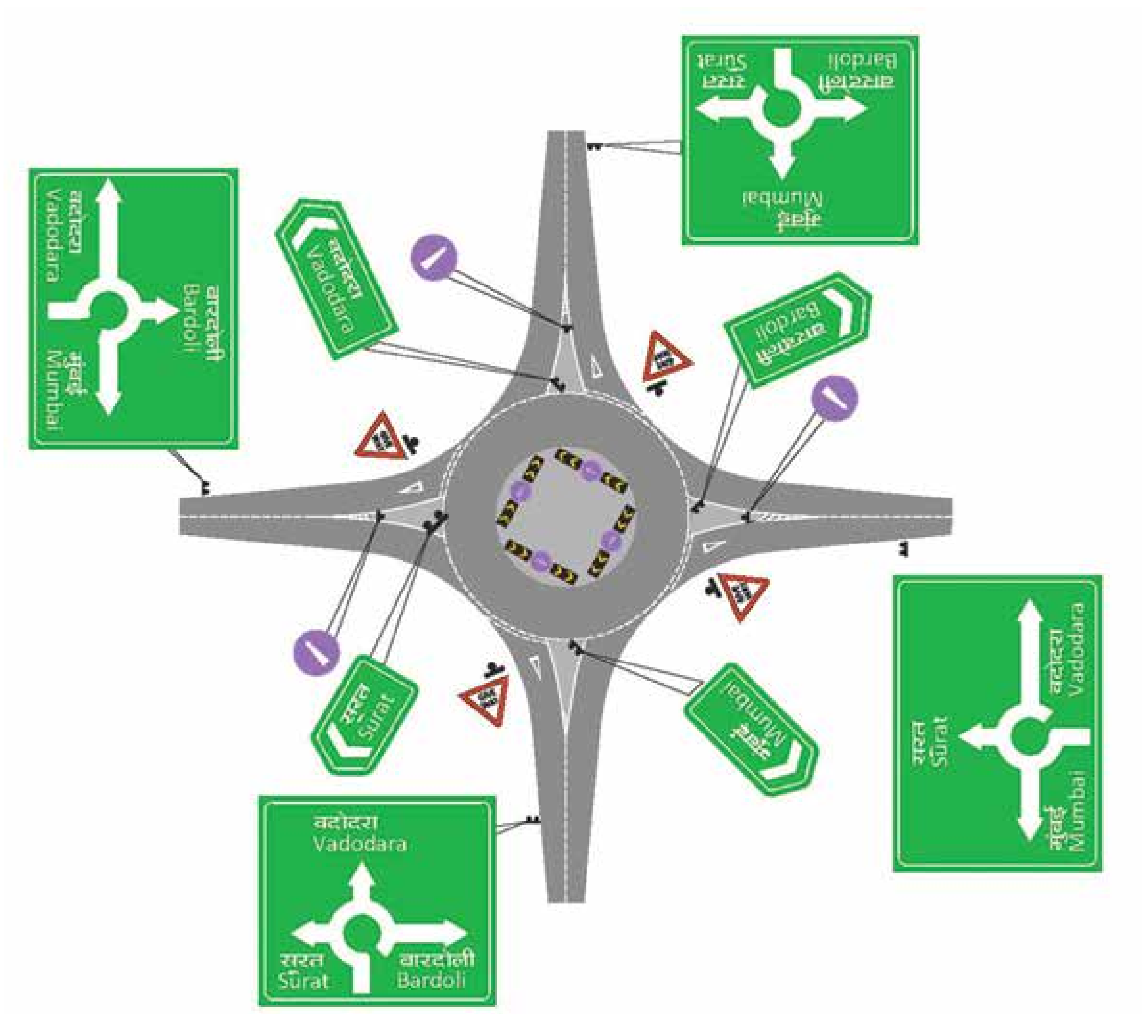


Fig. 6.19 Typical Sign and Marking plan for a 4-armed Single Lane roundabout

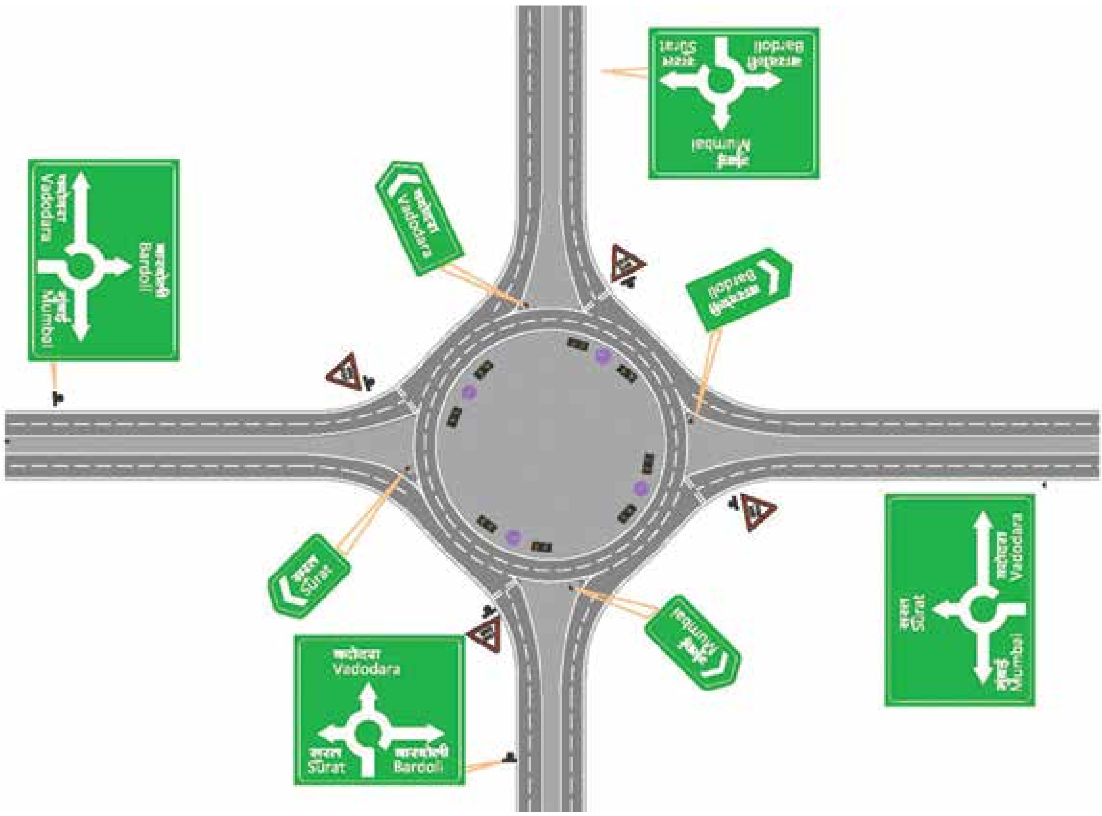


Fig. 6.20 Typical Sign and Marking plan for a 4-armed Rotary

7 NON-MOTORIZED TRANSPORTATION AT ROUNDABOUT

7.1 Pedestrians

It is essential that splitter islands (or medians) are provided for pedestrian crossing. In the planning and design of roundabouts special consideration should be given to the movement of pedestrians. Roundabouts are at least as safe for pedestrians as other forms of intersections. This is possible as pedestrians are able to cross one direction of traffic at a time by staging on the splitter islands. However, pedestrians must cross with care because, unlike traffic signals, roundabouts do not give priority to pedestrians over through traffic movements.

To minimize pedestrian accidents at crossings of entries and exits, the entry and exit speeds should be kept low. The best solution to achieve this is to provide small radius entry and exit curves.

Consideration may be given to providing priority crossings (e.g. zebra crossings), for pedestrians where:

- Pedestrian volumes are high;
- There is a high proportion of young, elderly or senior citizens wanting to cross the road; or

- Pedestrians are experiencing difficulty in crossing and are getting delayed excessively.

Other design considerations to enhance pedestrian safety at roundabouts include:

- Designing splitter islands which are as large as the site allows;
- Prohibiting parking on the approaches to the roundabouts to provide clear visibility;
- Providing street lighting which illuminates not only the circulating carriageways but also the approaches; and
- Locating signs and vegetation so as not to obscure “small” users of the road such as pedestrians.

However, where pedestrian volumes are high, serious consideration should be given to the use of an alternative intersection treatment. This is especially true where the pedestrian traffic consists of school children or the elderly. For the sake of universal accessibility and intimation to the road users, various surface treatment options and table top crossing can be provided.

7.2 Cyclists

Roundabouts can be designed to provide an acceptable level of safety for cyclists. However, the extent to which special geometric treatments and/or traffic control measures are needed to achieve an adequate level of safety will depend on:

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

Reducing the relative speed between entering and circulating vehicles, minimizing the number of circulating lanes, and maximizing the distance between approaches reduces the entering/circulating vehicle accident rates at roundabouts. These design concepts will also minimize entering/circulating vehicle accidents involving cyclists.

Separate cycle paths are safer than a bicycle lane within the road carriageway, particularly at highly trafficked roundabouts. This treatment has the added advantage of restricting widths through the roundabout enabling better entry curvature and deflection to be obtained.

Specific provision is not generally required at single lane roundabouts where vehicle speeds through the roundabout are less than 40 km/h. Special provision for cyclists is desirable where:

- The cumulative, approach traffic volume, exceeds 10,000 vehicles per day;
- There is a multi-lane roundabouts; or
- Vehicle speeds exceed 50 km/h through the roundabout.

Photo 7.1 Roundabout with Separated Bicycle Lanes

This can be achieved by:

- Providing a path of access for cyclists separated from the road carriage way as an alternative to the use of the road carriageway at the roundabout. In most instances, and particularly in the case of large roundabouts, it would be desirable for the path to be two-way, in order to provide cyclists with a convenient choice of route to the road carriageway, and hence encourage as many cyclists as possible to use the facility.
- Using footpaths located adjacent to the roundabout where separate provision is not possible. Fencing or landscaping between the path and carriage way, is necessary to prevent 'ride-out';
- Providing traffic signals for one or all entries to a roundabout, depending on the predominant paths of cyclists and other traffic or depending on the accident history;
- Providing a controlled crossing on critical approaches of very large roundabouts on busy roads or grade separation where cyclist demand is very high. A Live example is given in **Photo 7.1** and also **Fig. 7.1** where separate cycle path in a rotary location is shown.

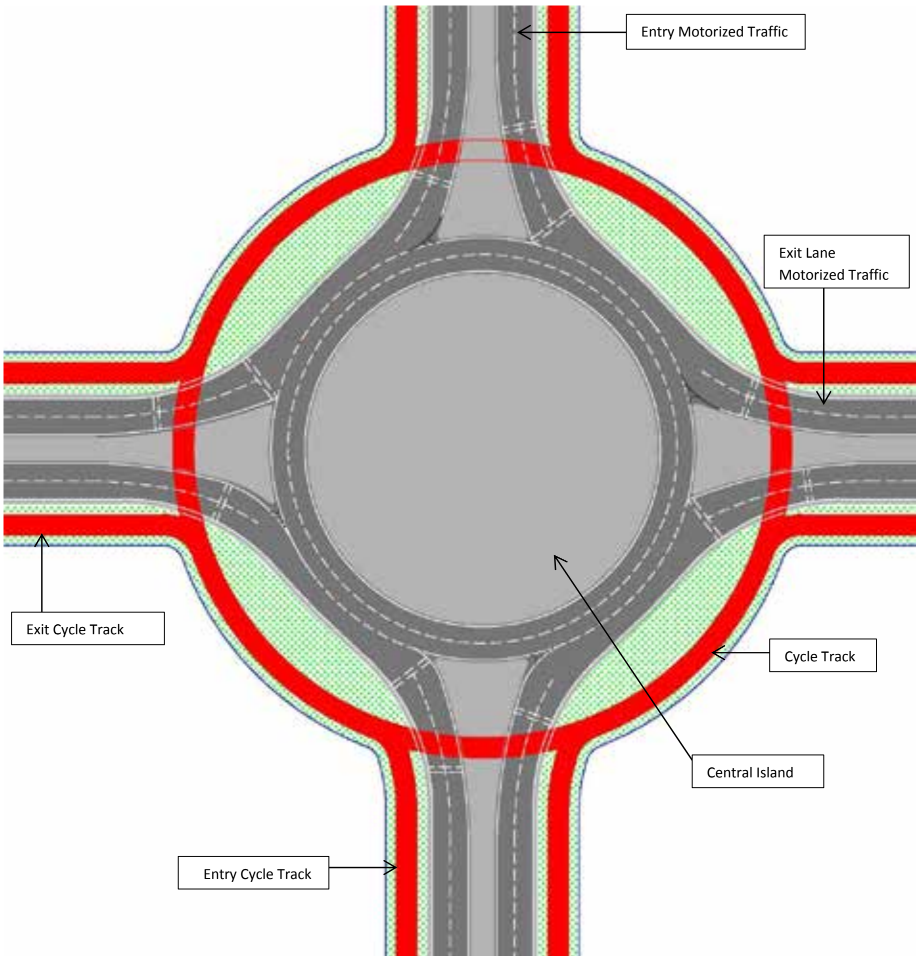


Fig. 7.1 Figure Showing Path of Cyclists Separated from the Carriageway

8 ROUNDABOUT PERFORMANCE INDICATORS

8.1 Critical Gap

Critical gap represents the minimum time interval in the circulating flow when an entering vehicle from approach can safely enter a roundabout. Thus, the driver's critical gap is the minimum gap that would be acceptable. A particular driver would reject gaps less than the critical gap and would accept gaps greater than or equal to the critical gap. Critical gap can be estimated on the basis of observations of the largest rejected and smallest accepted gap for a given intersection. Gap features:

- A gap is defined as the time span between two consecutive circulating vehicles that create conflict with an entering vehicle.
- The described time span is measured only when the entering driver is at the give way line when the gap begins.
- All gaps less than the critical gap would be rejected and all gaps greater than or equal to the critical gap would be accepted.

Fig. 8.1 shows the relationship between Diameter of Roundabout and Critical Gap

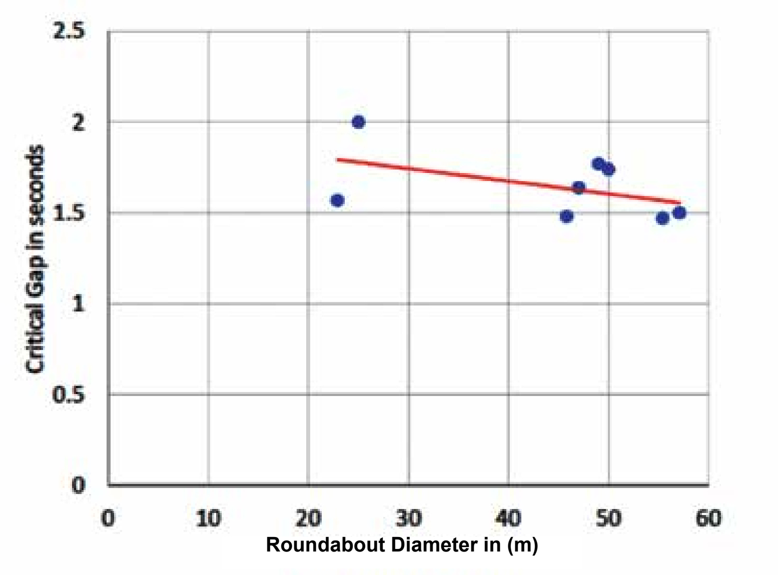


Fig. 8.1 Relationship between Diameter of Roundabout and Critical Gap

8.2 Follow-up Time

The time between the departure of one vehicle from the approach and the departure of the next vehicle using the same gap in circulating flow, under a condition of continuous queuing condition, is called the follow-up time. It is the headway that defines the saturation flow rate for the approach if there were no conflicting vehicles on movements of higher rank. In order to calculate entry capacity, it is required to calculate the critical gap and follow-up time for the roundabout. The critical gap and follow-up time at a roundabout primarily vary with the diameter of the roundabout. For the purpose of planning and design, the values of critical gap and follow-up time parameters for roundabouts of different diameters evolved based on the studies done across 18 roundabouts are presented in **Table 8.1**.

Table 8.1 Critical Gap and Follow-up Time for Different Diameter Roundabout

Diameter, D (m)	Critical Gap (sec)	Follow-up Time (sec)
20<D≤30	2.01	1.51
30<D≤40	1.87	1.40
40<D≤50	1.65	1.24
50<D≤70	1.61	1.21

[Source: CRRI (2017) "Indian Highway Capacity Manual (INDO-HCM)"]

8.3 Lag

A lag is the time span between an entering vehicle and opposing circulating vehicle. Many studies have shown that it is acceptable practice to combine lags and gaps into one data set for analysis.

8.4 Forced Gap

A forced gap occur when a vehicle enter the roundabout without giving enough consideration of the circulating traffic. The entering vehicles force themselves into the roundabout and circulating vehicles have to slow down or even stop to not crash into the entering vehicle. Forced gaps are mainly used by lorries that have trouble entering the roundabout due to lack of sufficient gaps.

8.5 Static Entrance

If a vehicle has to stop at the give way sign and wait for a sufficient gap to occur before entering the roundabout it is marked as static entrance.

8.6 Floating Entrance

If the driver finds a gap and does not have to stop at the give way sign the vehicle is defined as floating. It is only the first vehicle entering a gap that is a floating vehicle, the succeeding vehicles are follow-ups.

9 CAPACITY ESTIMATION

This section presents the process for determining the entry capacity of roundabout. The maximum flow rate that can be accommodated at a roundabout entry depends on two factors namely, the circulating flow on the roundabout that conflicts with the entry flow and the geometric elements of the roundabout.

When the circulating flow is low, drivers at the entry are able to enter the roundabout without significant delay. The larger gaps in the circulating flow are more useful to the entering vehicles and more than one vehicle may enter each gap. As the circulating flow increases, the size of the gaps in the circulating flow decrease, and the corresponding rate at which vehicles can enter also decreases.

Similarly, the geometric elements of the roundabout also affect the rate of entry flow. The most important geometric element is the width of the entry and circulatory roadways, or the number of lanes at the entry on the roundabout. Two entry lanes permit nearly twice the rate of entry flow as that of a single lane. Wider circulatory roadways allow vehicles to travel alongside, or follow, each other in tighter bunch and so provide longer gaps between bunches of vehicles. The flare length also affects the capacity. The inscribed circle diameter and the entry angle have minor effects on capacity. The capacity of roundabout is a function of entry flow and circulating flow. As driver behavior appears to be the significant variable affecting roundabout performance, consideration of critical gap and follow-up time is highly recommended to produce accurate capacity estimates. The following exponential model from US HCM (2010) can be used by the analyst for the estimation of entry capacity of roundabout:

$C = A * \text{Exp}(-B*Q_c)$ (Eq 9.1)

$A = 3600/T_f$ (Eq 9.2)

$B = (T_c - 0.5*T_f)/3600$ (Eq 9.3)

Where,

T_f = Follow-up time in seconds

T_c = Critical Gap in seconds

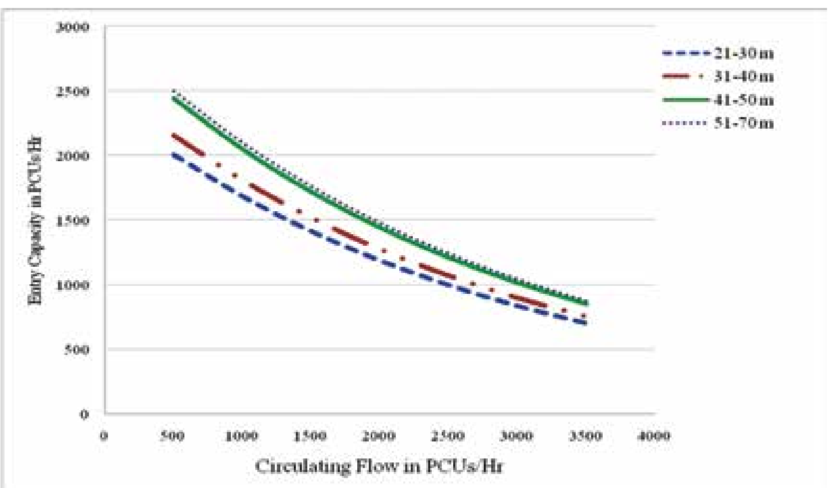
Q_c = Circulating flow in PCU/hr

Using the average critical gap and follow-up time presented in the earlier section, the entry capacity models/equations for varying range of diameters of roundabouts have been derived in the Indian Highway Capacity Manual (INDO-HCM) and presented in **Table 9.1**. The Nomograph for the direct estimation of entry capacity of the roundabouts of different sizes of circulating flow is presented in **Fig. 9.1**

Table 9.1 Entry Capacity Model for Varying Diameter of Roundabout

Diameter, D (m)	Critical Gap, T_c (s)	Follow-up Time, T_f (s)	$A=3600/T_f$	$B=(T_c - 0.5*T_f)/3600$	$C = A*\text{Exp}(-B*Q_c)$
20<D≤30	2.01	1.51	2388	0.00035	$C = 2388* \text{Exp}(-0.00035 * Q_c)$
30<D≤40	1.87	1.40	2567	0.00032	$C = 2567* \text{Exp}(-0.00032 * Q_c)$
40<D≤50	1.65	1.24	2909	0.00029	$C = 2909* \text{Exp}(-0.00029 * Q_c)$
50<D≤70	1.61	1.21	2981	0.00028	$C = 2981 * \text{Exp}(-0.00028 * Q_c)$

[Source: CRRI (2017) “Indian Highway Capacity Manual (INDO-HCM)”]



[Source: CRRI (2017) “Indian Highway Capacity Manual (INDO-HCM)”, Report submitted to CSIR]

Fig. 9.1 Entry Capacity for Varying Circulating flow

10 DELAY

The overall performance of roundabout is assessed with respect to total delay an individual vehicle experience while maneuvering through the roundabout. Sample speed profile along a network comprising of roundabout is shown in **Fig. 10.1**.

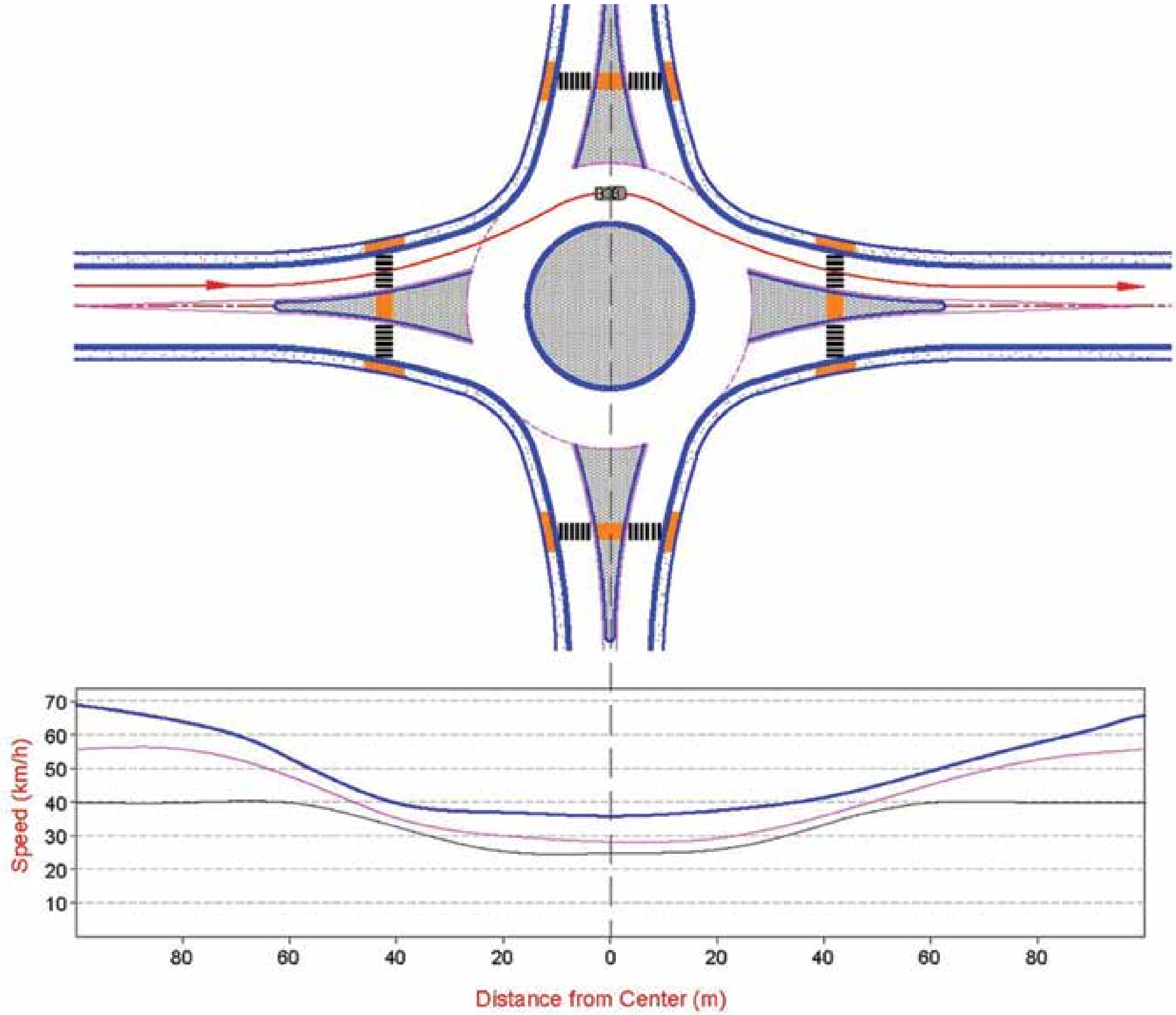


Fig. 10.1 Sample Speed Profile Along a Network Comprising of Roundabout

The different types of delay observed by maneuvering vehicles at roundabout is as follows:

- Queuing delay - The delay to drivers waiting to accept a gap in the circulating traffic.
- Geometric Delay - The delay to drivers slowing down to stop at the end of the queue and, after accepting a gap, accelerating to the negotiation speed, proceeding through the roundabout and then finally accelerating further to reach normal operating speed. It excludes the time to wait for an acceptable gap.

The comparison of delay offered by signalised intersection and roundabout is presented in **Fig. 10.2**.

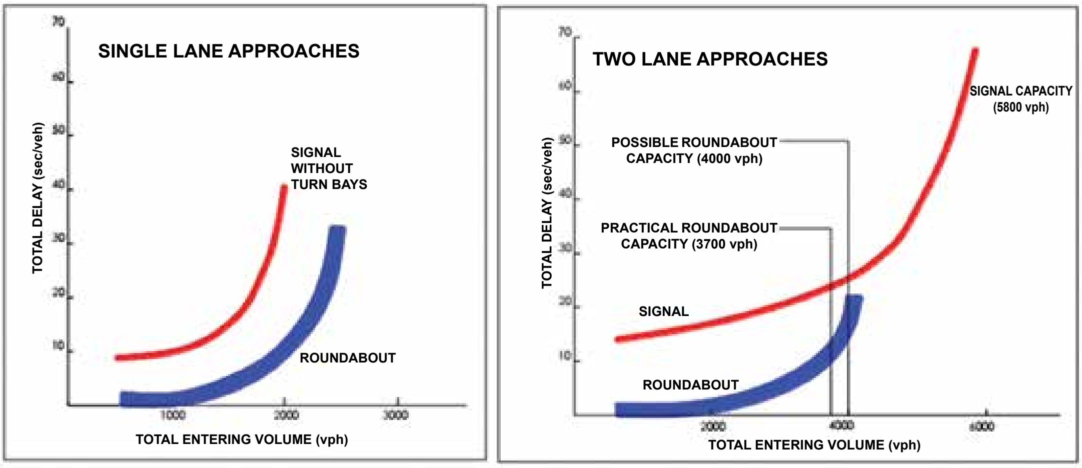


Fig. 10.2 Comparative Delay Offered by Signalized Intersection and Roundabout

11 LEVEL OF SERVICE (LOS)

The estimation of LoS is based on the vehicular delay model derived from studies conducted at 11 roundabouts by taking into account the delay experienced by the vehicle from entry point to reach the exit point of the roundabout.

The delay model empirically derived is as under:

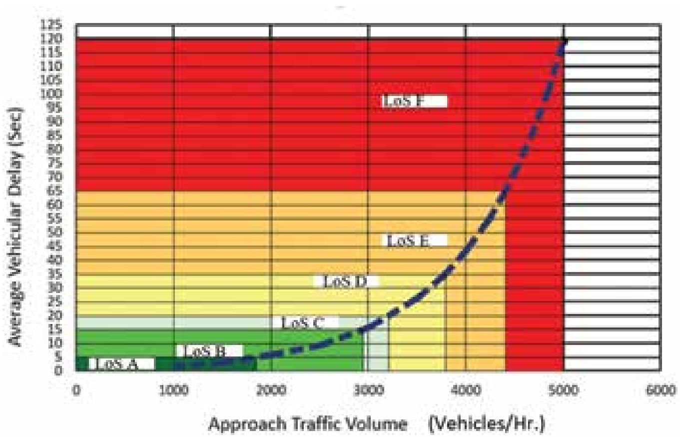
$y = 0.8*e^{0.001x}$ (Eq 11.1)

Where,

y= Vehicular Delay in seconds.

x= Total Approach Traffic Flow in Veh/hr.

Fig. 11.1 reveals the LoS derived for roundabouts from the above equation and cluster analysis.



[Source: CRRI (2017) "Indian Highway Capacity Manual (INDO-HCM)"]

Fig. 11.1 Relationship Between Approach Traffic Flow and Average Vehicular Delay

Based on observed vehicular delay at roundabout and prevailing traffic flow, LoS has been established by using clustering technique to represent the quality of traffic flow on roundabout. Accordingly, LoS for the roundabout are given in **Table 11.1**. If the volume to capacity (v/c) ratio of a lane exceeds 1.0 regardless of the delay, the LoS of the roundabout is defined as F.

Table 11.1 Level of Service for different Delay

LoS	Average Delay 'd' per Veh in sec
A	< 5
B	5 ≤ d < 15
C	15 ≤ d < 20
D	20 ≤ d < 35
E	35 ≤ d < 65
F	> 65

[Source: CRRI (2017) "Indian Highway Capacity Manual (INDO-HCM)"]

12 ILLUMINATION

In view of safety and security, streets should be well lighted. The roundabout must not be left unlit with one or more approaches being lit. Otherwise the driver may not be able to see the unlit roundabout while coming from a lit up approach arm. Reflective markers and signs should be used on the central island. Any raised islands or kerbing should also be illuminated if possible. Otherwise, reflective markers are a must. The exit arms should have an 'illumination transition zone' where the intensity of lighting gradually decreases. When the driver exits the well illuminated roundabout, he/she should be able to adapt to the dark environment of the exiting arm.

A lot of vehicles go out of control on roundabouts. So, adequate clear zones should be maintained so that there are no hazards for such vehicles. Therefore, lighting poles should not be placed on small channel islands and left hand perimeter just exiting from the roundabout. For details on illumination, reference may be made to IRC:SP:90 "Manual for Grade Separators & Elevated Structures".

13 LANDSCAPING

The form and layout of the roundabout should not get obscured to the driver; therefore use of appropriate plantation is required. The central island should appear prominent, so that the driver is able to distinguish the central island from the surroundings. Small Channel Islands should not have trees planted on them. Landscaping must be done carefully so as to maintain the clear line of sight.

The plantation along the approach and exit arm should be low in height so as to maintain a clear line of sight for the driver. Large, fixed landscape elements such as big trees, rocks, sculptures, etc. should be avoided in areas vulnerable to vehicle run off. Landscaping in corner radii areas should be done to channelize pedestrians to crosswalk areas and discourage pedestrians from jaywalking or from crossing to the central island.

For more details on clearances, reference may be made to IRC:SP:21 “Guidelines on Landscaping and Tree Plantation”.

Fig. 13.1 Typical landscape details on roundabout.

14 SAFETY

14.1 General Considerations

In general, a well-designed roundabout is the safest type of intersection. ‘Before and after’ type studies have shown that in general, fewer vehicle accidents occur at roundabouts than at intersections containing traffic signals, stop or give way signs. The primary reason for this is that the potential relative speeds of vehicles are considerably lower for a well-designed roundabout than for other types of at-grade intersections.

Conversely, a poorly designed roundabout with little entry curvature or deflection results in high speeds through the roundabout creating high potential relative speeds between vehicles. Multiple vehicle accident rates at these roundabouts can actually be higher than for an equivalent at-grade intersection. Therefore it is important to give special attention to the design of the geometry of roundabouts.

Within the context of low overall accident rates for roundabouts, single vehicle accident rates at roundabouts are high compared to other intersection types. This is because roundabouts consist of a number of relatively small radii horizontal curves for each travelled path through the roundabout. Drivers travel on these curves with quite high speed. Single vehicle accidents, which predominantly involve out-of-control vehicles, increase as the required amount of side friction decreases.

Because of the relatively high number of out-of-control vehicles, it is desirable to have adequate amounts of clear zone where there are no roadside hazards on each side of the carriageway. Roadside hazards common at roundabouts include light and power poles, large trees and sign supports etc. If roadside hazards cannot be located outside the required clear zone, consideration should be given to making them frangible. If it is not possible to remove roadside hazards or make them frangible, protecting them with safety barriers are a hazard in themselves and are the least desirable option. In addition, safety barriers in the vicinity of the holding line often obscure visibility to circulating vehicles. Central lighting is often preferred for this reason as well as for economy.

14.2 Speed Control

14.2.1 The entering/circulating vehicle accident rate on any particular approach is largely related to the potential relative speed of entering and circulating vehicles. Minimizing the potential relative speed of entering and circulating vehicles will minimize the entering/ circulating vehicle accident rate. The potential relative speed of entering and circulating vehicles should be limited to 40 km/h.

14.2.2 The potential relative speed of entering and circulating vehicles on any particular approach can be reduced by:

- Reducing the entry curve radius.
- Providing a smaller radius entry curve on the preceding approach arm.
- Providing greater deflection through the roundabout.
- Increasing the central island diameter.
- Providing more separation between arms.
- Decreasing the entry and exit widths.

14.2.3 The exiting/circulating vehicle accident rate at any particular exit point of multi-lane roundabouts is predominantly related to the potential relative speed of exiting and circulating vehicles. Minimizing the relative speed of exiting and circulating vehicles will minimize the exiting/circulating vehicle accident rate.

14.2.4 Speed Consistency can be achieved by following general guidance given in **Fig. 14.1**, where R1 is the entry path radius on the fastest through path, R2 is the circulating path radius, R3 is the exit path radius, R4 is the Right turn path radius and R5 is the left turn. In the fastest path, it is desirable that entry path radius R1 to be smaller than R2. Exit Radius R3 should not be less than R1 or R2 to minimize loss of control crashes. Radius of right turn R4 ensure that maximum speed difference between entering R1 and circulating R2 is no more than 20 kmpkh. The fastest left turn R5 shall be below the roundabout design speed and not more than 20 kmph of conflicting R4 path radius.

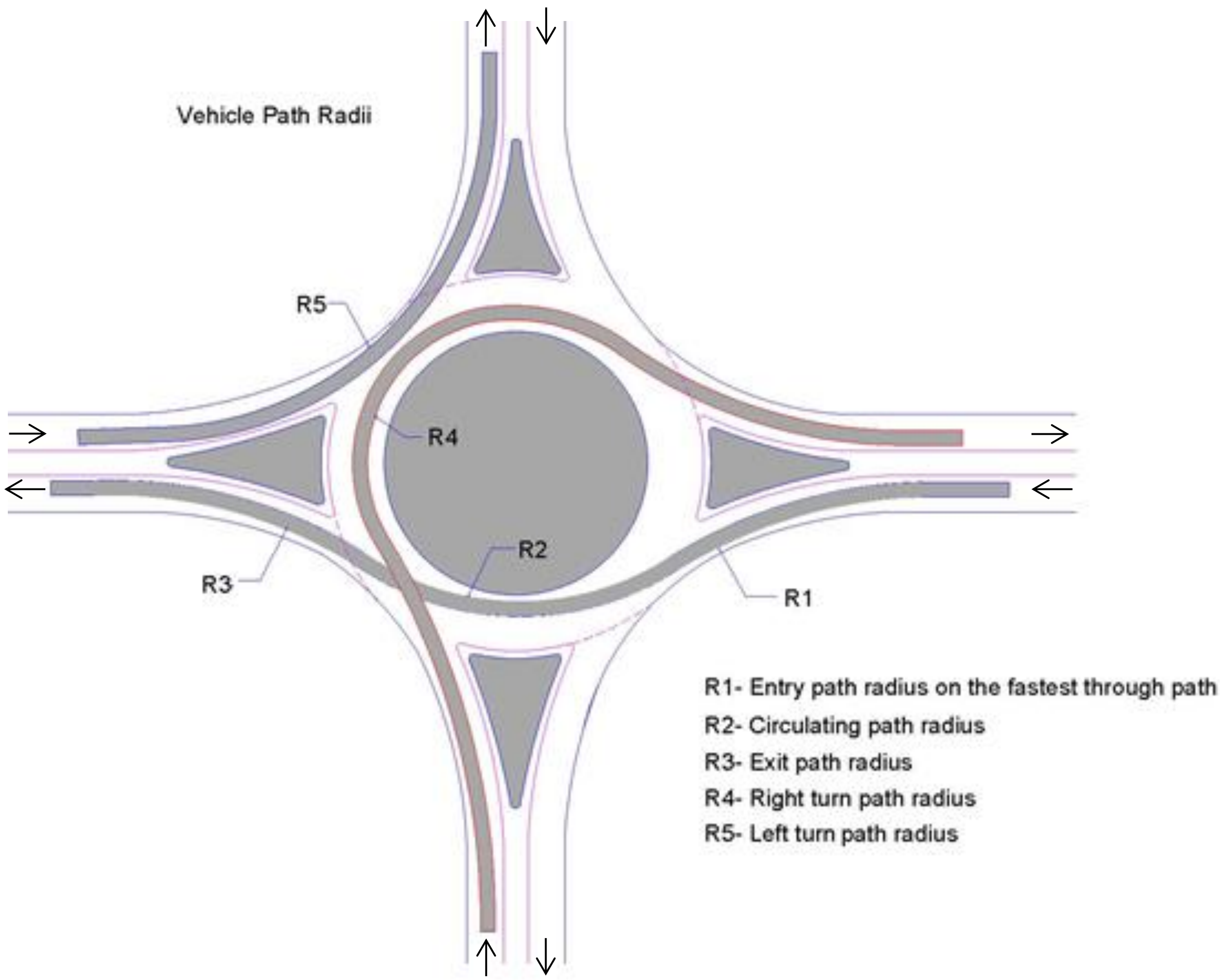


Fig. 14.1 Vehicle Path Radii

REFERENCES

1 Road Planning & Design Manual, First Edition, Department of Transport and Mains Road, Queensland 2014

2 Indian Highway Capacity Manual, 2016

3 Planning Level Guidelines for Modern Roundabouts, Center for Transportation, Research and Education, Iowa State University, U.S.

4 IRC:SP:90-2010 “Manual for Grade Separators & Elevated Structures”

5 IRC:SP:21-2009 “Guidelines on Landscaping and Tree Plantation”

6 IRC:35-2015 “Code of Practice for Road Markings”

7 IRC:67-2012 “Code of Practice for Road Signs”

8 IRC:SP:42-2014 “Guidelines of Road Drainage”

9 IRC:SP:50-2013 “Guidelines on Urban Drainage”

10 IRC:65-1976 “Recommended Practice for Traffic Rotaries”