Accommodating Vulnerable Road Users in Roundabout Design

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ABSTRACT: Roundabouts, under the right circumstances, are quickly proving themselves to the North American transportation engineer as a viable intersection treatment for both urban and rural roadways. The design of roundabouts is a complex procedure involving several variables, which need to be addressed to ensure a design is safe and has adequate capacity. A principle based design approach that balances the competing objectives of safety, capacity, and cost allows the designer to achieve a good solution for a particular site. Ideally, these design principles provide the engineer the flexibility to tailor a design to meet differing needs. For example, a slower entry and/or exit speed for increased pedestrian safety, or surfacing treatments for the visually impaired, or geometric configurations promoting higher capacity.

Because good design is not a one-size fits all approach, following a 'prescriptive' standard design methodology applied across the entire range of roundabouts will not result in balanced designs. Creating added confusion for designers is the fact that Europe, Australia, and the UK each have different sets of design principles, in some cases contradictory, which have evolved based on varying levels of research.

Roundabouts have their own set of advantages and disadvantages when comparing pedestrian and cyclist treatments to those provided at conventional intersections. The literature shows, given a properly designed roundabout facility, that vehicular and pedestrian safety at roundabouts, is almost always improved when compared to conventional intersections. Results regarding cyclist safety are somewhat mixed. Due to the elimination of conflict points at roundabouts and the lower speed differentials compared to conventional intersections, accident severity for all users is often significantly reduced when collisions occur, although frequency may increase.

1. INTRODUCTION

Roundabout design and implementation has recently become more prevalent as an intersection treatment in North America, especially since the Federal Highway Administrations published *Roundabouts: An Informational Guide*. Other state and provincial agencies have followed suit and have developed their own design guidelines to assist design practitioners with local implementation. Notwithstanding the amount of emerging information on roundabout design, and the fact that the provinces of Quebec and British Columbia have their own guidelines at various stages of maturity, a nationally adopted Canadian roundabout design guideline does not currently exist.

The design of roundabouts is a complex procedure involving several variables that need to be addressed to ensure a design is safe and has adequate capacity. A principle based design approach that balances the competing objectives of safety, capacity and cost are the best tools available to a designer attempting to achieve a satisfactory solution for a particular site. When appropriate and depending on the characteristics of the site, careful consideration must be given to vulnerable road users as well. This can cause added confusion for the designer since different design guides often present different design principles; and road user safety in roundabouts is highly dependent on geometry, pavement markings, signing, public education, enforcement and many other related factors.

For the purpose of this discussion, vulnerable road users will be considered to include only pedestrians and cyclists. It should also be recognized that the vulnerability of a particular road user is based on the ability of that user to survive a crash with a conflicting user. For example, a pedestrian would be considered the vulnerable user when involved in a vehicle / pedestrian conflict.

The following discussion is not intended as a set of roundabout edicts to be followed during design; instead, comparisons in how some readily available design guides accommodate vulnerable road users are presented for consideration. Some general observations, which are anecdotal at best, are made that will desirably stimulate a roundabout designer to contemplate pedestrian and cyclist movements through these intersections.

2. BACKGROUND

When examining a road hierarchy it is important to understand the different roles each type of roadway plays in the movement of vehicles, pedestrians or cyclists (1). For example the primary purpose of a freeway or arterial is vehicular movement while local subdivision roads may need to cater equally to vehicles and pedestrians. A balanced approach to roundabout design not only considers the functional classification of the roadway corridor but also the different types of road users and accommodates them in a logical manner consistent with infrastructure treatments typically found at traditional intersections.

Strategic safety management is a developing approach that can be used to identify and minimize discrepancies between the engineering characteristics of a roadway and its functional classification. However, it is often where these discrepancies are most prevalent that high levels of accidents occur (1). It is inevitable that as North American design practitioners consider roundabouts as viable intersection treatments they will be confronted by a situation where the roadway in question serves multiple functions. It is, therefore, essential that roundabout designers understand the differences between vehicle, pedestrian and cyclist conflicts in roundabouts compared to conventional intersections.

2.1 Conflicts in Operation

The FHWA Roundabouts Informational Guide provides a thorough discussion and comparison of vehicle, pedestrian and bicycle conflicts and will not be repeated here; however, as the underlying theme of this discussion is the vulnerable road user, a cursory review is warranted.

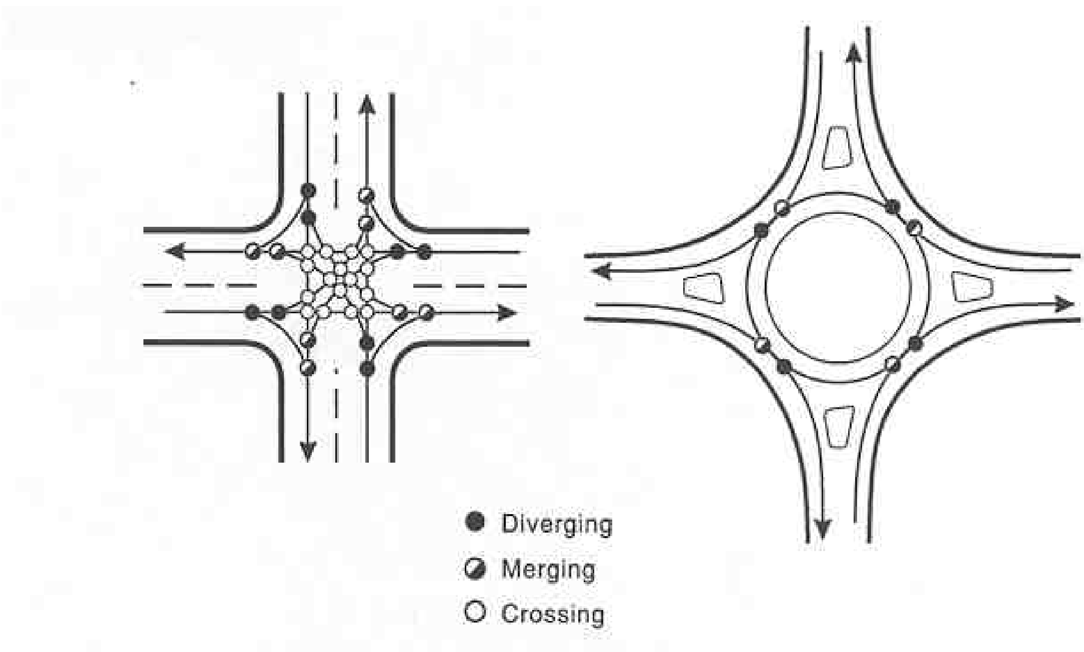

FIGURE 1 – VEHICLE / VEHICLE CONFLICTS FOR 4-LEG INTERSECTIONS (1)

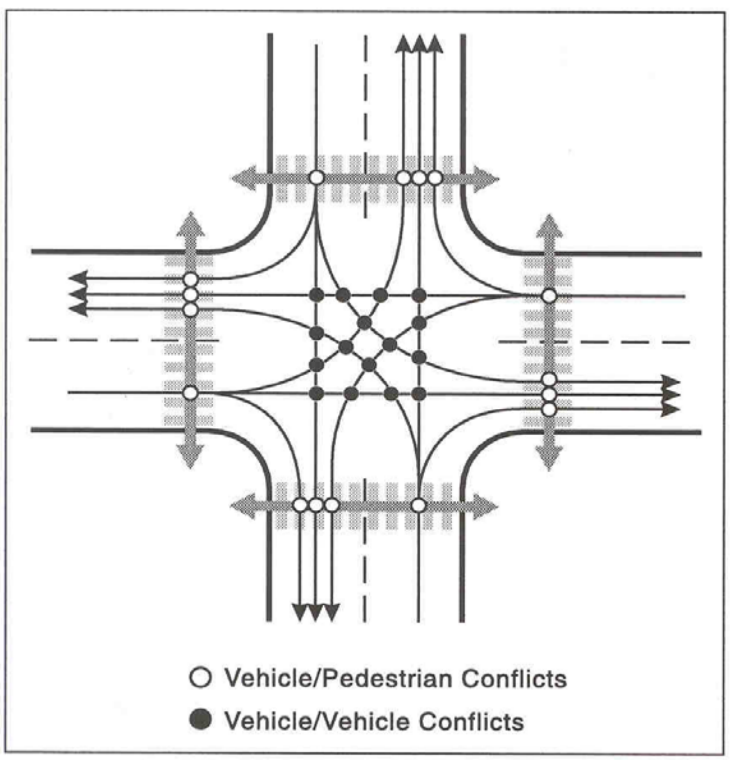

FIGURE 2 – VEHICLE / PEDESTRIAN CONFLICTS AT A 4-LEG SIGNALIZED INTERSECTION (1)

Figure 1 shows single lane vehicle / vehicle conflicts at a conventional and a roundabout intersection. Both configurations have four legs; and, as seen in the figure, the number of conflict points in a roundabout drops from 32 to 8 when compared to the traditional intersection. It is intuitive that the frequency of crashes is related to the number of conflict points. Reducing the number of potential conflict points, all else being equal, reduces the number of potential conflicts or crashes.

The number of pedestrian conflicts also varies significantly between conventional intersections and roundabouts. Figure 2 presents vehicle / pedestrian conflicts at a signalized intersection, while Figure 3 identifies the same at a roundabout. Comparing the figures reveals that the potential vehicle / pedestrian conflicts at a roundabout number only 8 while the conventional intersection total is 16. Both scenarios represent single lane approaches. It is also apparent that a pedestrian navigating a conventional intersection must be cognizant of traffic approaching from multiple directions while the roundabout allows the pedestrian to focus on only one vehicle movement at a time due to the pedestrian refuge area provided by the splitter island.

Cyclists, depending on how they choose to navigate an intersection (as a vehicle or as a pedestrian), are exposed to similar conflicts as either vehicles or pedestrians. Cyclists are, however, subject to additional conflicts where their path overlaps with that of a motor vehicle. Shown, as black dots in Figure 4, are the conflicts unique to bicycles at a conventional intersection, while the white dots represent cyclist conflicts similar to those of a motor vehicle. Figure 4 illustrates a cyclist making a left turn, negotiating the single lane approach intersection as a vehicle and also as a pedestrian.

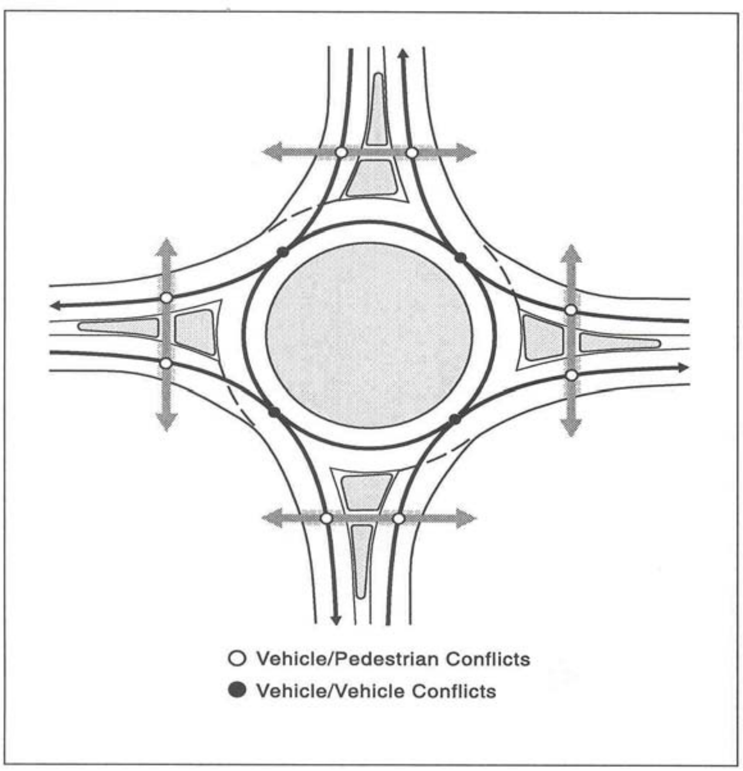

FIGURE 3 – VEHICLE / PEDESTRIAN CONFLICTS AT A 4-LEG ROUNDABOUT INTERSECTION (1)

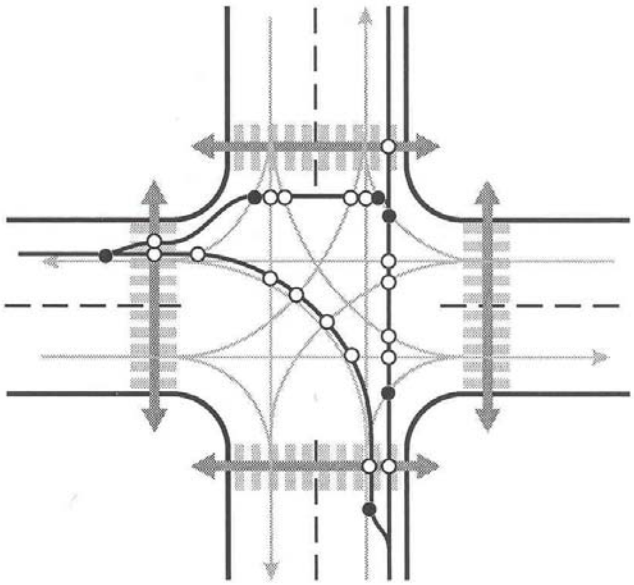

FIGURE 4 – BICYCLE CONFLICTS AT A CONVENTIONAL INTERSECTION (1)

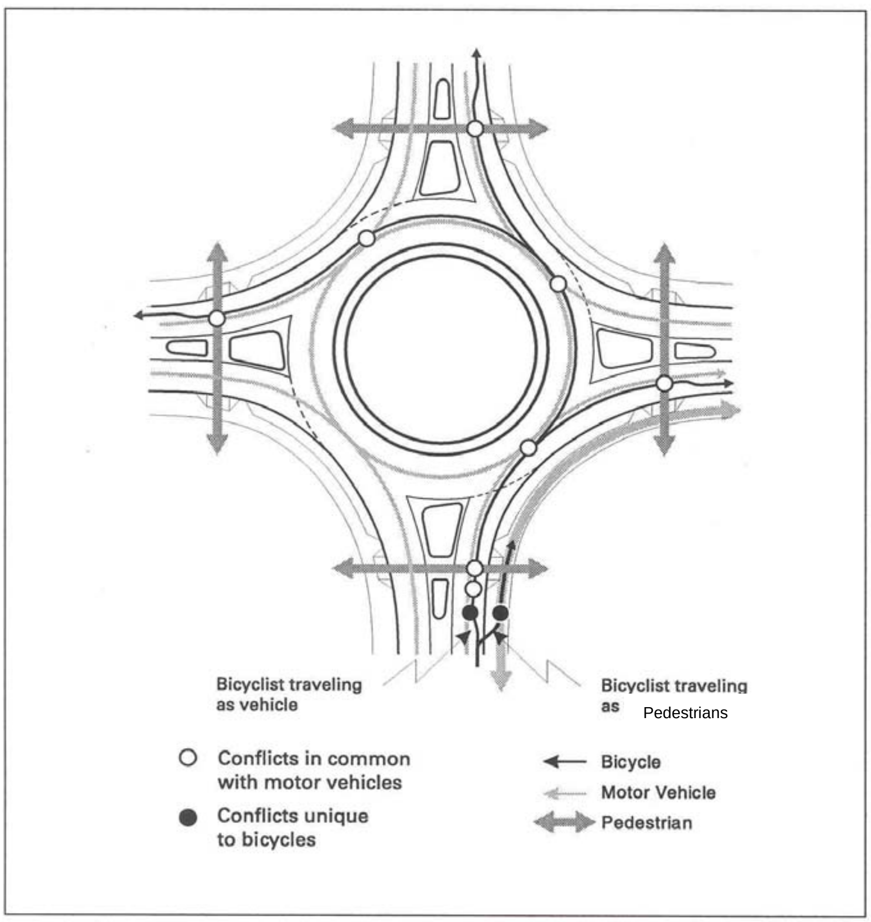

FIGURE 5 – BICYCLE CONFLICTS AT A ROUNDABOUT INTERSECTION (1)

As is the case for a conventional intersection, bicycles also have the option of negotiating a roundabout intersection as either a pedestrian or a vehicle and are thereby subjected to similar conflicts as their respective counterparts. Bicycles are, however, exposed to an additional merging conflict when approaching a roundabout intersection as a vehicle. Moreover, a bicycle / pedestrian conflict must also be noted when the cyclist elects to negotiate the roundabout as a pedestrian; although in terms of hierarchy, in this case, the pedestrian is the more vulnerable road user. Figure 5 shows bicycle conflicts at a roundabout when traveling as a vehicle.

The expurgated review of intersection conflict scenarios presented in the preceding paragraphs reveals the benefits provided to vulnerable road users when navigating roundabouts compared to conventional intersections. The number of potential conflict points in all cases is reduced for roundabouts although no correlation has been made to the frequency or severity of collisions. The following sections will explore causation between the differences in number of conflicts and pedantically review the approach taken by some of the more accessible design guidelines available to the North American designer.

3. DESIGN ALTERNATIVES FOR THE VULNERABLE ROAD USER

Many jurisdictions including some in Canada are beginning to produce and disseminate information on the design of roundabouts often based on Australian, European or UK source material. The FHWA produced a fairly comprehensive and generally accepted roundabout informational guide. Even though it is based on research, a polemical approach is used to address some design aspects. Nevertheless, the amount of design material available compounded with the differences in local acceptation of the same, make it difficult for designers to fully appreciate the various treatments used in accommodating vulnerable road users in roundabout design.

3.1 Literature Review

Before delving into a shoal comparison of design treatments for vulnerable road users, consideration must be given to the relationships among vehicle travel speeds, speed differentials between road users and safety. When considering roundabout design it should be understood that safety of all road users, including pedestrians and cyclists, is dependent on the balance of the design. That is, the geometry, traffic characteristics, spatial orientation, topography, signing, pavement markings, predominant user characteristics, user education, enforcement and other factors all play an important role in the overall performance of a roundabout intersection.

It is no surprise, given the number of roundabouts in operation, that roundabout installations in Australia, Continental Europe and the UK have been the focus of numerous studies pertaining to their overall safety performance.

Sweden has nearly 1000 roundabouts in operation. Although they recognize roundabouts as a very safe type of intersection, they have studied accident and injury risks at roundabouts with different configurations to better understand the nuances of safe design (3). The Swedish National Road and Transport Research Institute conducted three separate studies: speed analysis study in 536 roundabouts, safety study of cyclists and pedestrians in 72 roundabouts, and a motorist safety study in 182 roundabouts. They found that multilane roundabouts had more cyclist accidents than their single lane counterparts although this was likely due to the volume difference in both vehicles and cyclists at those facilities. They also found that central island diameters greater than 10 m were safer than those smaller than 10 m (3).

The authors found that the roundabout installations studied provided equal or better pedestrian safety than their conventional intersection counterparts. They also concluded that single lane roundabouts were much safer than two-lane configurations (3). This is likely due to the increased distance the pedestrian is required to cross before reaching the splitter island, and the added number of conflicts and sight restrictions resulting from the additional lanes at entry and exit. It is conceivable that two-lane roundabout configurations would inevitably have more generous entry and exit geometry resulting in higher fastest path speeds through the intersection. Moreover, they found traffic volumes and speed have the greatest influence on crashes with lower speeds resulting in a lower number of injured per accident (3).

In general, design considerations for pedestrians and cyclists have been marginal at best on North American roadways. Design features that enhance the safety of vulnerable road users separate them from vehicles by either time or space, make them more visible, and reduce vehicle speeds. Any combination of these engineering countermeasures, or even applying these measures independently, will improve vulnerable road user safety and help reduce the likelihood of a collision (4, 5, 6).

In 1995 Brown published a fairly comprehensive summary of UK roundabouts design and research experience in a two-volume set. The material provided on pedestrian and cyclist facilities is not exhaustive; however, he has noted that channelization of pedestrian movements away from the entries of roundabouts is preferable. UK experience indicates a queue of 2 to 3 between a pedestrian crossing and the yield line located at the circulatory roadway improves pedestrian safety. In general, the UK has found roundabouts offer an impressive safety record for all users with the exception of cyclists. They have observed that cyclists proportion 15% of all accidents even though they comprise only 2% of the overall traffic flow (8).

Persaud et al. performed a before and after study on 24 conventional intersections in the United States that were converted to roundabouts. The authors used Bayesian statistics, which accounts for regression to the mean, to estimate crash reductions resulting from the roundabout installations. Their study found a 39% reduction for all crashes regardless of severity and a 76% reduction in injury crashes. Reductions in severe and fatal crashes were found to be approximately 90% (9).

It is well known that the safety performance of roundabouts, in particular the safety of roundabout vulnerable road users, is related to the number of conflicts, speed at which vehicles enter the intersection, speed differential between road users, geometric configuration and numerous other factors. North American and international studies have generally found that roundabout intersections enhance road user safety and are effective in reducing crash severity. The following section describes pedestrian and cyclist treatments that are explicitly identified in select North American roundabout design guidance literature. The primary source is the FHWA Informational Guide and reference will be made to the recently published State of Wisconsin Roundabout

Facilities Development Manual, BC Ministry of Transportation Draft Technical Bulletin, and the Caltrans Design Information Bulletin.

4. DESIGN TREATMENTS FOR PEDESTIRANS AND CYCLISTS

In designing pedestrian and cyclist facilities at roundabouts, consideration must be given to a variety of competing objectives including user mobility, convenience, safety, vehicle operations and capital cost (1). Admittedly, it would be difficult to produce a design guide that adequately addresses all of the potential competing design objectives for roundabout installations given the unique characteristics of the North American road network. Because the requirements in one location of a province, or even a city, differ from those nearby, any documented design heuristics need to furnish the transportation designer with enough flexibility to generate an appropriate solution tailored to the site in question.

The FHWA Informational Guide identifies pedestrian convenience, pedestrian safety and vehicular operations in the roundabout as some of the primary factors warranting consideration in locating pedestrian crossing treatments. Figure 6 shows the minimum splitter island dimensions for a single lane roundabout. The splitter island provides pedestrian refuge during a crossing movement, helps channelize approaching traffic, impedes wrong-way movements, and separates the directional stream of traffic. As shown in the figure, the recommended minimum offset from the yield line to the beginning of the crossing location is identified as 7.5 m.

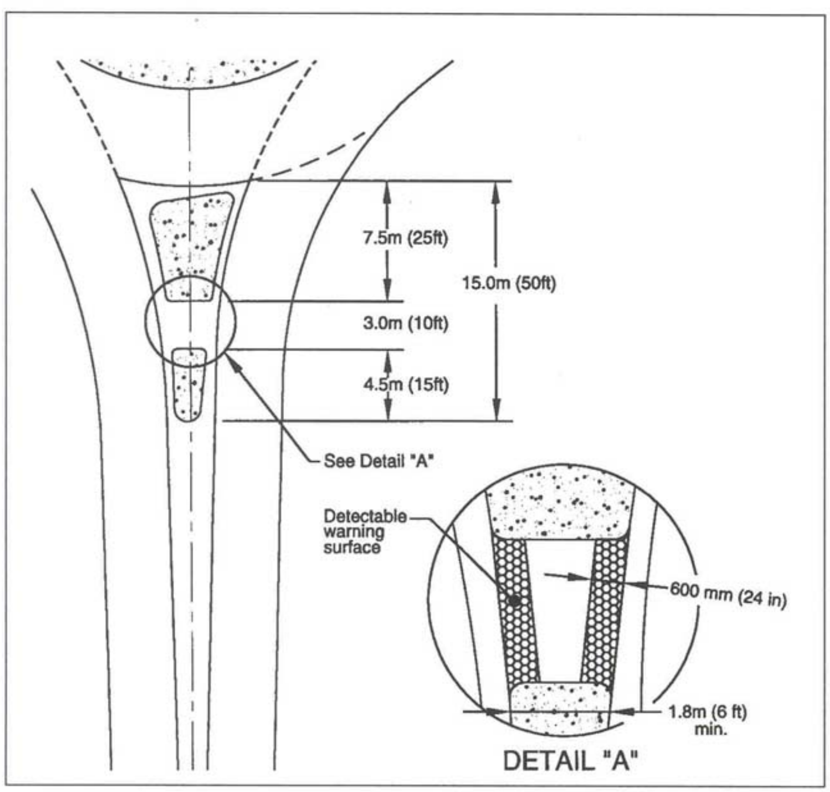

FIGURE 6 – RECOMMENDED SPLITTER ISLAND DIMENSIONS (1)

Recall the UK recommendation of providing sufficient space for 2 to 3 vehicles between those features (8). It is possible that the dimensional variation between sources is due to differences in the average vehicle length or perhaps a greater tolerance to increased crossing distance by the UK pedestrian compared to their US counterpart. Caltrans suggests that the FHWA guide may provide excessive separation between pedestrian crossing locations and the yield line indicating a minimum of 6 m as being acceptable (10). The BC and Wisconsin design guides do not reference a minimum dimension or discuss locating these pedestrian treatments in any detail.

Figure 6 also shows a detectible warning surface delineating the travel lane from the refuge area. This is essentially a texturing treatment used to clarify the crossing location for those who are visually impaired. Caltrans advocates this treatment and mandates its use at all pedestrian crossing locations.

Figure 7 shows sidewalk and pavement marking treatments for crosswalk facilities. Note the 'zebra' striping shown between the sidewalk ramp and refuge area. Caltrans requires 'ladder' striping instead, emphasizing the benefits of consistently conveying the same message to users at both conventional and roundabout intersections.

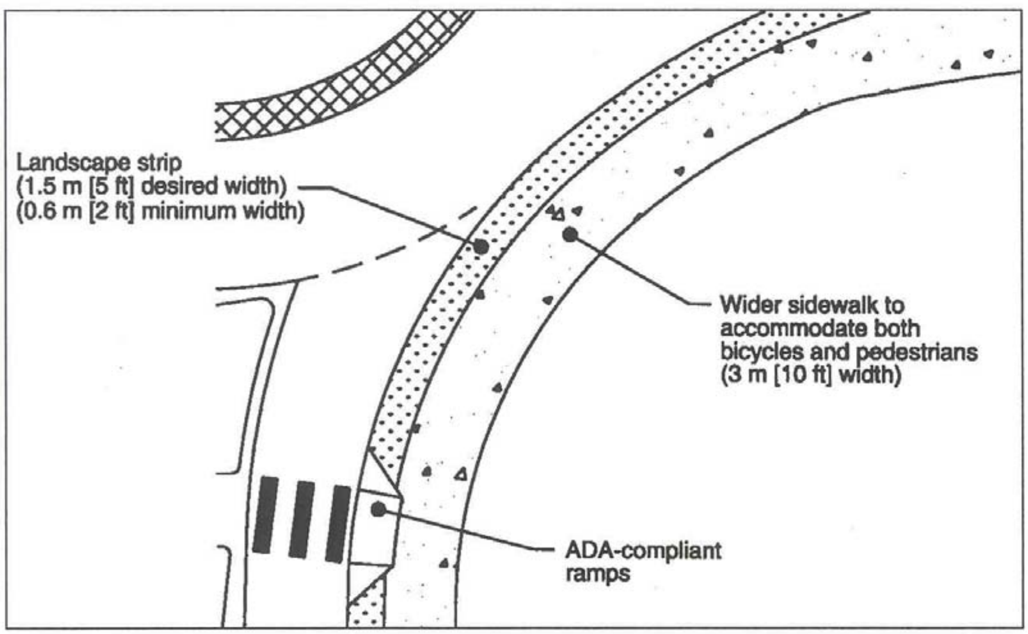

FIGURE 7 – ROUNDABOUT SIDEWALK TREATMENT (1)

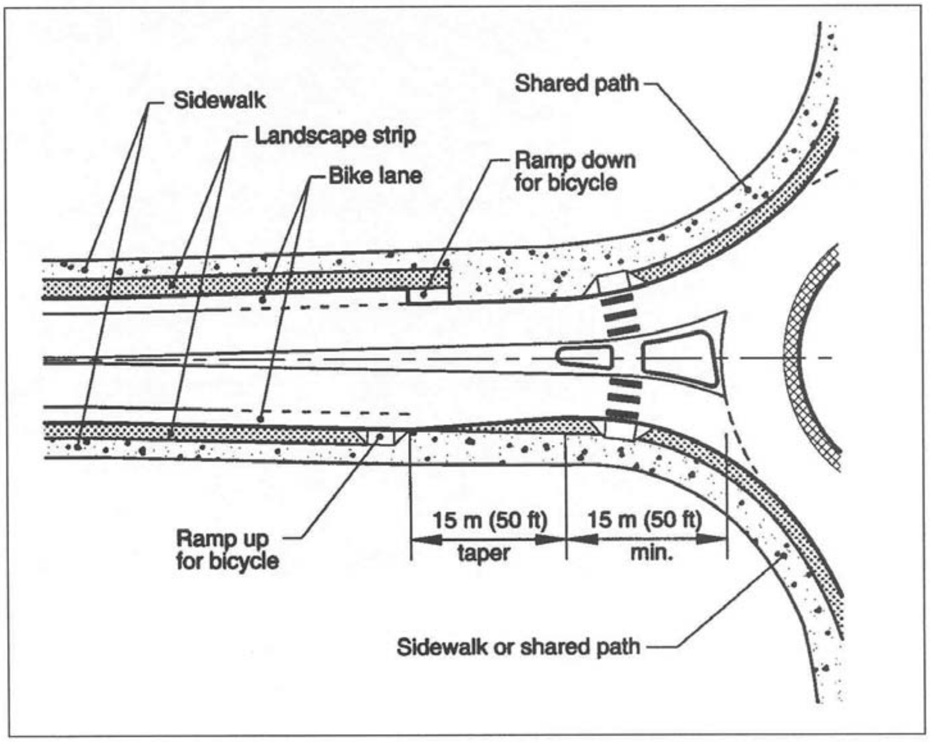

FIGURE 8 – ACCOMODATIONS FOR CYCLISTS AT ROUNDABOUTS (1)

Figure 8 depicts a series of treatments that can be used to accommodate cyclists at single lane roundabouts. Note that the termination of the bike lane at the approach is directly adjacent to a ramp that could be easily used by the cyclist who would prefer negotiating the roundabout as a pedestrian. Drop ramps are provided at the departure in the direction of travel to allow cyclists to continue off the shared sidewalk with as little inconvenience as possible. The Caltrans treatment for cyclists is identical to the FHWA configuration shown in Figure 8 with the exception of the approach ramp from the bike lane to the sidewalk. Caltrans specifies a ramp up angle between 30 and 45 degrees to the travel lane orientation. This would conceivably encourage cyclists to navigate the roundabout as a pedestrian without dismounting.

4.1 Other Considerations

Although the Wisconsin guide does not provide pictorial guidance in locating and detailing pedestrian or cyclist facilities, it does provide some valuable discussion on the subject. The emphasis is placed on a design principles approach that, when applied correctly, will result in a roundabout configuration with slow entries and exits improving pedestrian safety. Reference is made to adjacent land use, pedestrian volumes, demographics and even pedestrian delay. It is clear from the discussion provided in their guide that providing a safe pedestrian crossing location, balanced with the rest of the design objectives, is not a simple task.

With regard to cyclists, Wisconsin notes that one of the challenges in designing and integrating appropriate facilities for bicycles is the range of skills and abilities among users. What would satisfy and be preferred by an experienced cyclist is not necessarily appropriate or adequate for a novice. There are complexities between vehicle and cyclist interactions that further challenge the transportation designer.

5. SUMMARY

Every roundabout intersection has its own unique set of characteristics that compel transportation engineers to use sound engineering judgment in finding an appropriate design solution. Roundabouts provide their own advantages and disadvantages for both pedestrians and cyclists when compared to conventional intersections. Table 1 highlights some of these advantages and disadvantages.

TABLE 1 – ROUNDABOUT ADVANTAGES AND DISADVANTAGES FOR PEDESTRIANS (4)

Advantages	Disadvantages
• Vehicle speed is reduced as compared to other intersections.	• Vehicle traffic is yield controlled; therefore, traffic does not necessarily stop. May cause hesitation by pedestrians.
• Pedestrians have fewer conflict points than at other intersections.	• May cause anxiety in pedestrians who are not confident judging gaps in traffic.
• Splitter islands and resulting pedestrian refuges allow users to focus on one direction of traffic at a time.	• Crossing locations and set backs from the yield line often result in a longer distance of travel for pedestrians.
• Crossing movement can be accomplished with less wait time than at conventional intersections with many protected phases.	• Not widely used yet in North America providing significant challenges for the visually impaired.

Roundabouts also present several advantages and disadvantages for cyclists similar to those identified above. There are, however, significant concerns regarding cyclist safety and the literature has shown that care must be taken in properly designing bicycle facilities at roundabouts or these intersections may be detrimental to safety.

Roundabouts have the potential to provide the North American transportation designer with a safe, efficient and viable intersection solution. A roundabout design approach based on sound principles is required to balance the competing objectives of safety, operations and cost; and as shown by the widespread use of roundabouts in other parts of the world, acceptance of these intersection treatments can be gained through sound implementation.

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