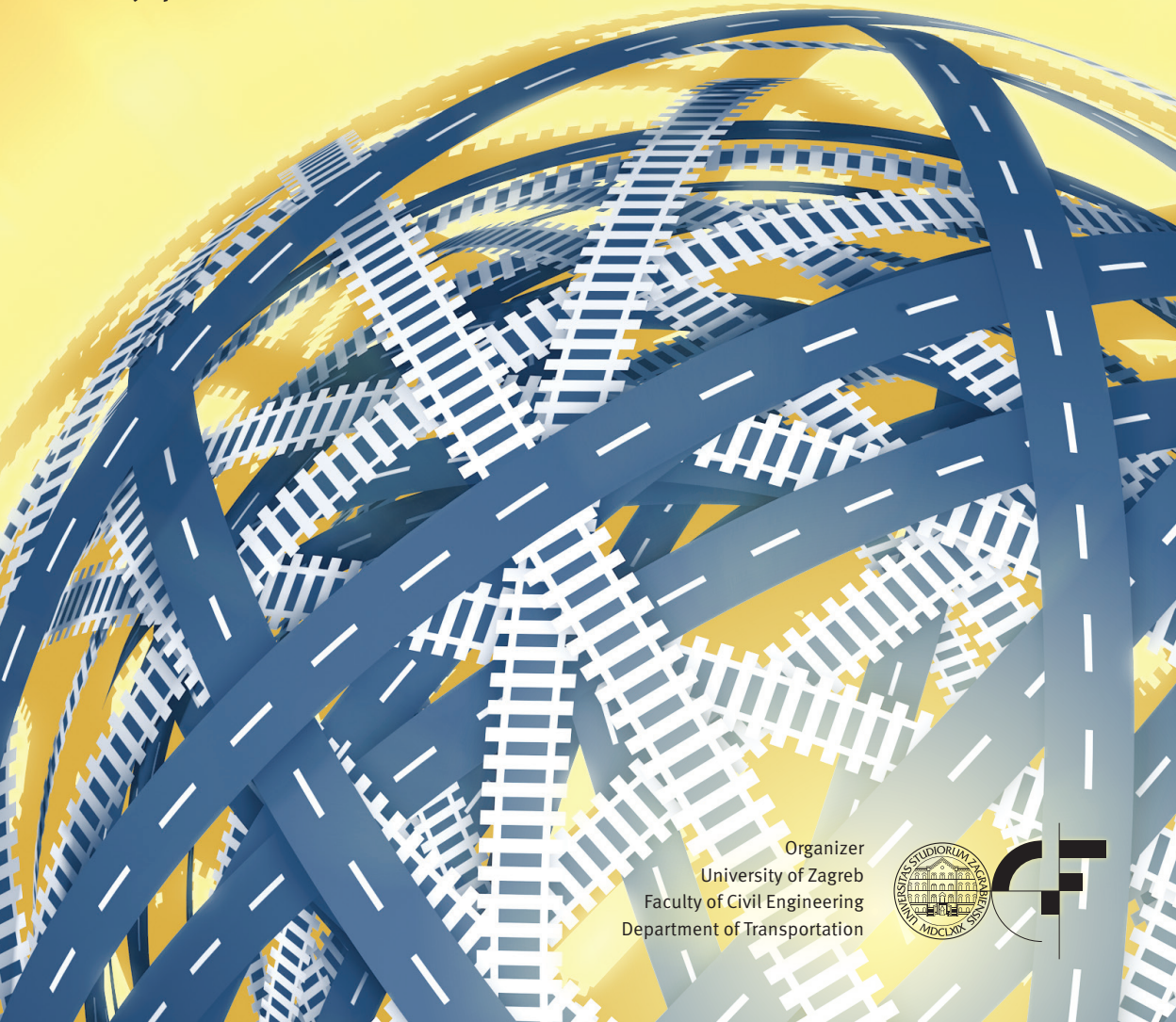


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4th International Conference on Road and Rail Infrastructure
23-25 May 2016, Šibenik, Croatia

Road and Rail Infrastructure IV

Stjepan Lakušić – EDITOR



Organizer
University of Zagreb
Faculty of Civil Engineering
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REVIEW OF FASTEST PATH PROCEDURES FOR SINGLE-LANE ROUNDABOUTS

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Abstract

Good safety performance, improved capacity, and numerous environmental benefits of modern roundabouts, in respect to signalised and stop-controlled intersections, have led to their rapid implementation on road traffic networks around the world. A well-designed roundabout reduces vehicle speeds upon entry and achieves smooth speed profile by requiring vehicles to negotiate the roundabout along a curved path. With that in mind, roundabout geometric design must include prediction of entry and circulation speed by estimating the fastest path into and through the circulatory roadway. Despite the fact that overall roundabout performance depends on the quality of the design features, inconsistencies in design standards and practices concerning the aforementioned performance check can be observed. In this paper, various fastest path analysis procedures for single-lane roundabouts (described in several European and US standards and guidelines) are presented, and the diversity of the approaches is pointed out.

Keywords: roundabouts, traffic safety, geometric design, fastest path

1 Introduction

Roundabout design is an iterative process that consists of: identification of initial design elements, performance checks (swept path, speed, and visibility analyses), and final design details. Although numerous studies confirmed the link between benefits of modern roundabouts and the quality of their design, inconsistencies in design standards and practices concerning the aforementioned performance checks can be observed [1-13].

It is well known that deflection is the most important roundabout design feature that controls the vehicular speed and affects the safety and capacity [3]. In other words, roundabout geometry has to reduce the speed on the approaches, limit the speed through the circulatory roadway and allow a safe transition back to the free flow [4-6]. The influence of deflection on roundabout performance is usually evaluated by defining the radius (or radii) of the centreline of a vehicle traveling along the so-called fastest path through the roundabout and then calculating the vehicle speed [4]. This theoretical fastest path is representative of most used trajectory by drivers under free flow conditions when minimizing their driving discomfort [3]. At first glance this roundabout performance check seems straightforward: firstly fastest path is defined, then the path radii is measured or calculated, and at the end the vehicle speed is estimated based on speed-radius relationship. However, inconsistencies in design standards and practices concerning procedures for the definition of the deflection, construction of the fastest path, vehicle speed estimation and the speed profile requirements can be observed. In this paper, the focus is set on displaying key elements of the vehicle speed analysis procedures for single-lane roundabouts described in several European and US standards and guidelines. Also, the diversity of the approaches concerning the fastest path analysis is pointed out.

2 Speed analysis procedures

Speed analysis on roundabouts can be conducted using 3 different approaches:

- by measuring the roundabout's geometry features and checking the achieved deflection (described in [7] – German guidelines);
- by measuring the roundabout's geometry features and then calculating the path radii and vehicle speed (described in [8-10] – Dutch, Slovenian and former Croatian guidelines);
- by constructing the fastest paths through the roundabout, measuring the path radii and then calculating the vehicle speed (described in [6], and [11-13] – American, Serbian, new Croatian, and French guidelines).

Essential input parameters used in these analyses are: relevant movements, deflection or fastest path elements, and minimum clearances from curbs. These parameters are presented below.

2.1 Definition of relevant movements

In general, the fastest path is defined for a vehicle traversing through the entry, around the central island, and out the relevant exit, for all approach lanes. However, analysed documents differ in terms of definition of relevant movements:

- guidelines [7-9] suggest that the deflection and/or speed analysis on the roundabout is conducted only for the straight passage of the vehicle, as shown in Figure 1 a,
- guidelines [13] define two movements that should be checked: straight passage through the roundabout and right-turn movements, as shown in Figure 1 b,
- according to [6], [11] and [12], the fastest paths must be drawn for all movements: straight passage, left-turn movements and right-turn movements, as shown in Figure 1 c.

Left-turn movements generally represent the slowest of the fastest paths (path with the minimum radii), and that right-turn movements may be faster than the through movements at some roundabouts [6]. Because of that, these movements should not be neglected during the fastest path and speed analysis. It is advisable that at least two movements are investigated for each approach: straight passage through the roundabout and right-turn movements (Figure 1 b).

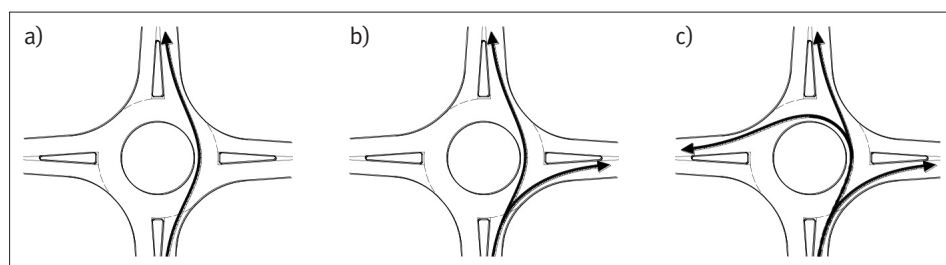


Figure 1 Relevant movements

2.2 Deflection and vehicle speed estimation

Beside the definition of relevant movements, documents presented in this paper differ in their approach to the estimation of vehicle speed and deflection impact assessment.

German guidelines [7] do not propose estimation of vehicle speed on roundabouts. According to this document, influence of the deflection is analysed by measuring the roundabout's ge-

ometry features: the entrance width (B_z) and the distance (D) between the edge of the central island and the right side of the splitter island on the access road, measured at the tangent point (Figure 2 a). If the distance (D) is greater or equal to double entrance width ($2B_z$), the roundabout's deflection is satisfactory.

According to guidelines [8-10], estimation of vehicle speed on roundabouts is conducted by measuring the roundabout's geometry features: the distance between the tangent of entry radius and the tangent of the exit radius (L), and the distance between the edge of the central island and the right side of the lane of the access road, measured at the tangent point (U) (Figure 2 b). With the aid of the L and U sizes the radius of the driving curve is calculated. Theoretical attainable vehicle entry speed is then defined on the basis of the speed-radius relationship, which is presented in the chapter 4.

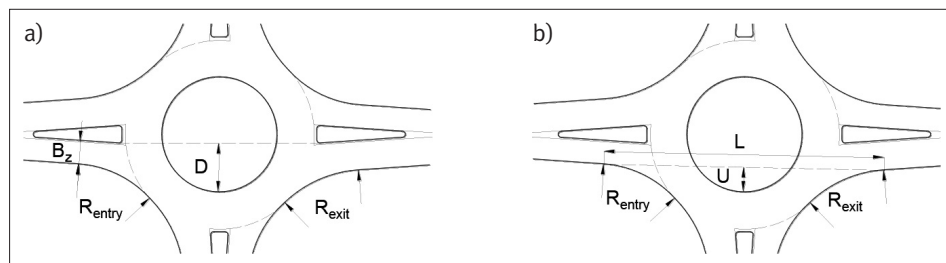


Figure 2 Deflection impact assessment

French guidelines [13] do not give detailed instructions on the construction of the fastest path (apart from their minimum clearances and maximum allowed radii), and claim that the dimensions of standard intersections listed in them result in preferable deflections and consequently vehicle speed. The estimation of vehicle speed on roundabouts is based on the construction of the fastest paths only according to [6], [11] and [13]. This procedure is composed from following steps: construction of the fastest path on the analysed roundabout, measurements of path radii (R_p), and estimations of vehicle speed based on speed-radius relationship. The fastest path is defined as the smoothest, flattest path possible for a single vehicle, in the absence of other traffic and ignoring all lane markings, traversing through the entry, around the central island, and out the relevant exit [6].

2.3 Fastest path construction and elements

A true fastest path is comprised of a series of consecutive spiral curves that are tangent to each other [14]. It can be drawn by hand, or constructed by means of CAD software. Drawing the fastest paths by hand on scaled representation of the intersection results in natural, smooth vehicle path through the roundabout, but it requires significant engineering experience and skill. The minimum radii are measured on sketched path using suitable curve templates or by replicating the path in CAD and using it to determine the radii. If CAD software is applied, the fastest path can be constructed by application of 3rd degree (cubic) splines (Wisconsin method, [15-17]), or short straights and reverse curves (ACHD method, [14]), as shown in Figure 3. 3rd degree splines are piecewise polynomials of 3rd degree with function values and 2nd derivatives that agree at the points (nodes) where they join. When constructing the fastest path by this method, nodes must be defined in such way that they result in spline curve tangent with the prescribed minimum clearances, or curb offsets [17], described in the next subchapter. When short straights and reverse curves are used, the resulting path is not intended to trace the actual fastest path because it is replacing spirals with arcs and tangents [14]. In each case, the results are intended to provide arc radii that match the actual fastest path spiral radii at their tightest points.

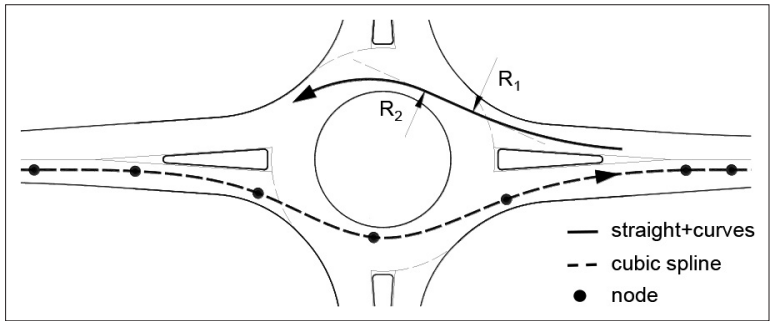


Figure 3 Fastest path construction elements

2.4 Minimum clearances

No matter what approach (and/or elements) is used in the construction of the fastest path, it should be drawn with the prescribed distances to the particular geometric feature (Figure 4): (a) painted edge line of the splitter island, (b) a right curb on the entrance and exit of the roundabout, and (c) a curb of the central island [6]. The fastest path minimum clearances defined in the analysed documents are shown in Figure 4.

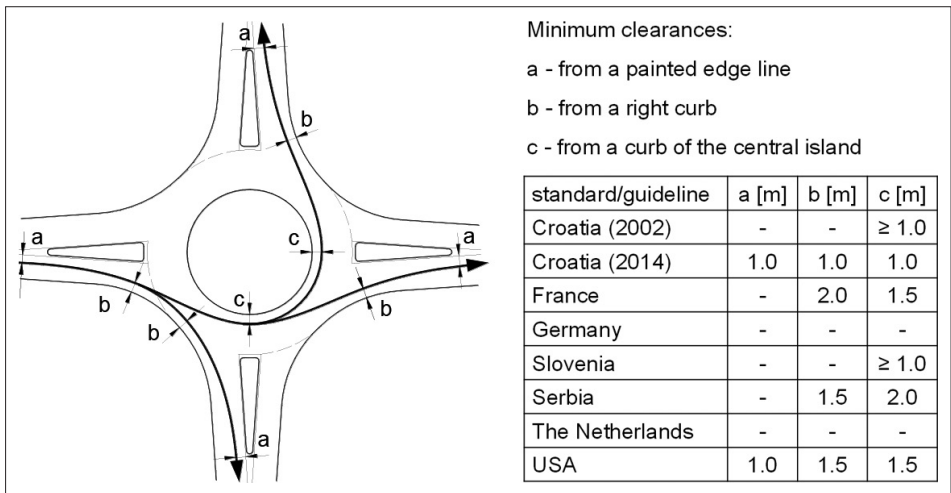


Figure 4 Fastest path minimum clearances

It should be noted that 1.0 m clearance does not always ensure unhindered passage of a passenger car (that is 2.0 m wide) through the roundabout. Because of that, larger minimum clearances are recommended, for instance the ones defined by [6]: a = 1.0 m, b = c = 1.5 m.

3 Fastest path critical radii

According to [13], a trajectory's deflection (i.e. the fastest path critical radius) is the radius of the arc that passes at a prescribed distance away from the edge of the central island and from the edges of the entry and exit lanes. The radius of this arc should be less than 100 m. According to [8-10], the radius of the driving curve is calculated with the aid of the following formula:

$$R = \frac{(0.25 \cdot L)^2 + (0.5 \cdot (U+2))^2}{U+2} \quad (1)$$

where R [m] is the radius of the driving curve, L [m] is the distance between the tangent of entry radius and the tangent of the exit radius, and U [m] is the deviation, shown in Figure 5 a. The design of the roundabout is correct if the radius of the driving path is between 22 and 23 m. According to [6], [11], and [12], in order to determine the design speed of the roundabout, the smallest radius along the fastest path must be defined. According to [6], smallest radius usually occurs on the circulatory roadway as the vehicle curves to the left around the central island (R_4 , Figure 5 b). Nevertheless, in order to achieve required entry, circulating, and exit speeds, appropriate critical radii must be obtained on each segment of the fastest path. Because of that, all five critical path radii must be checked for each roundabout approach ([6], [11], [12]):

- the entry path radius (R_1) which is the minimum radius on the fastest through path prior to the entrance line;
- the circulating path radius (R_2), which is the minimum radius on the fastest through path around the central island;
- the exit path radius (R_3), which is the minimum radius on the fastest through path into the exit;
- the left-turn path radius (R_4), which is the minimum radius on the path of the conflicting left-turn movement;
- the right-turn path radius (R_5), which is the minimum radius on the fastest path of a right-turning vehicle.

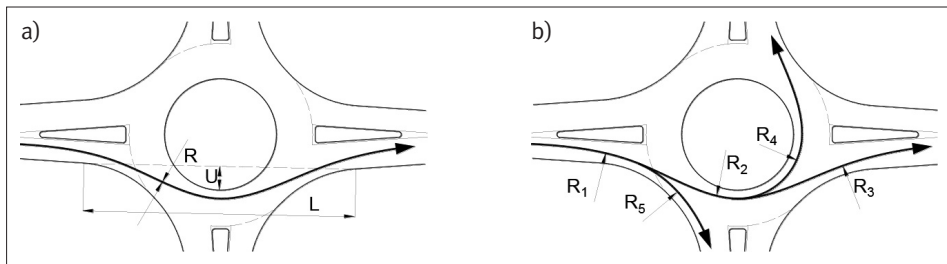


Figure 5 Fastest path critical radii

In order to achieve required speed differential between conflicting traffic movements, entry path radius (R_1) must be larger (but not significantly [18]) than circulating path radii (R_2 and R_4), and at the same time smaller than exit path radius (R_3). Also, circulating path radius (R_2) must be smaller than exit path radius (R_3) [6]. According to [18], approximate values of the radius of the conflicting left-turn movement (R_4) vary from 11 to 19 meters, while the right-turn radius (R_5) can vary from 54 to 73 meters, depending on the size of the analysed single-lane roundabouts.

4 Speed-radius relationship

Vehicle speed estimation is based on speed-radius relationship. The relation between the speed in the vehicle path curve and the radius of this curve according to [8-10], and [12] is:

$$V_i = 4.7 \cdot \sqrt{R_i} \quad (2)$$

where V_i [km/h] is the predicted design speed, and R_i [m] is the radius of curve.

According to [6] and [11], the speed of a vehicle is affected not only by the radius of vehicle path curve, but also both superelevation and the side friction factor. Speed can be calculated using the following formula:

$$V_i = \sqrt{127 \cdot R_i \cdot (f \pm e)} \quad (3)$$

where V_i [km/h] is the predicted design speed, R_i [m] is the radius of curve, f [-] is side friction factor (it varies with vehicle speed and can be determined in accordance with AASHTO guidelines [19]), and e [-] is superelevation. According to the analysed documents, superelevation values are assumed to be +0.02 [6] or +0.025 [11] for entry and exit curves and -0.02 [6] or -0.025 [11] for curves around the central island.

Design speed (V_i) calculated for different path radii (R_i) by means of formulas (2) and (3) (with assumed superelevation $e = +0.025$), and differences (Δ) between them are shown in the Table 1. It can be noted that formula (2) results with larger design speed than formula (3), and that these discrepancies grow with the increase of the path radius.

Table 1 Calculated design speed

V_i [km/h]	R_i [m]									
	15	20	25	30	35	40	45	50	55	60
eq. (2)	28.7	33.1	37.0	40.5	43.8	46.8	49.6	52.3	54.9	57.3
eq. (3)	25.4	28.3	30.7	33.0	35.0	36.8	38.5	40.0	41.4	42.7
Δ	3.3	4.8	6.3	7.5	8.8	10.0	11.1	12.3	13.5	14.6

5 Design speed and speed differential on roundabouts

According to the analysed documents, if the calculated speed is above the recommended threshold, roundabout design elements should be modified. These recommended values differ significantly: they vary from 25 to 40 km/h according to [12], from 30 to 35 km/h according to [9] and [10], from 21 to 46 km/h according to [18], and according to [13] the overall geometric design should not allow speeds greater than 50 km/h.

In addition to appropriate maximum speeds, speed checks should consider the speed differential between conflicting traffic movements ([6], [11], [18]). Namely, large differentials between entry and circulating speeds may result in an increase in single-vehicle crashes due to loss of control [18]. According to [6], in order for vehicles to safely negotiate the roundabout, the maximum speed differential between movements should be approximately 15 to 25 km/h, while according to [11] this value should be approximately 10 to 20 km/h. It should also be noted that the fastest path methodology does not represent expected vehicle speeds, which can vary substantially based on vehicles construction, driving abilities, and tolerance for gravitational forces [18].

6 Conclusions

For a roundabout to operate safely and efficiently, the most critical design objective should be achieving appropriate vehicular speeds through the intersection. A review of vehicle speed analysis procedures for single-lane roundabouts given in this paper showed the significant discrepancies between the speed analyses approaches, values of key input parameters and speed, and consequently the speed analyses results. This highlights the need for further research on the relationships between roundabout geometric design elements and vehicle speed (especially for local traffic conditions). Results of this research would provide benefits in terms of performance based design of suburban roundabouts, and therefore should be incorporated in their design guidelines.

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