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Sight distance evaluation on suburban single-lane roundabouts

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Preliminary report

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The issue of sight distance evaluation on suburban single-lane roundabouts is analysed. An overview of regulations, standards and guidelines applied in Austria, France, Croatia, USA, Serbia, and Switzerland, which describe procedures for determining the necessary sight distance, is given. Influential parameters for defining clear vision areas for intersections, defined in the aforementioned documents, are presented in detail. An emphasis is placed on the diversity of sight distance evaluation approaches, and test results obtained on a theoretical example of a suburban roundabout are commented on.

Key words:

roundabouts, sight distance, regulations, guidelines, standards, clear vision areas

Prethodno priopćenje

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Ispitivanje preglednosti na izvangradskim jednotračnim kružnim raskrižjima

U radu se obrađuje problematika preglednosti na izvangradskim kružnim raskrižjima. Dan je pregled postupaka određivanja potrebne preglednosti, prikazanih u propisima, normama i smjernicama koji vrijede u Austriji, Francuskoj, Hrvatskoj, SAD-u, Srbiji i Švicarskoj. Detaljno su prikazani utjecajni parametri i postupci određivanja polja preglednosti definirani u razmatranim dokumentima. Istaknuta je raznolikost u pristupima ispitivanju preglednosti te je dan komentar rezultata ispitivanja provedenih na teorijskom primjeru izvangradskog kružnog raskrižja.

Ključne riječi:

kružna raskrižja, preglednost, propisi, smjernice, norme, polje preglednosti

Vorherige Mitteilung

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Untersuchung der Übersichtlichkeit bei außerstädtischem einspurigem Kreisverkehr

In dieser Arbeit wird das Problem der Übersichtlichkeit bei außerstädtischem einspurigem Kreisverkehr betrachtet. Es wird eine Übersicht der Verfahren zur Ermittlung benötigter Übersichtlichkeit gegeben, die gemäß Regelwerken, Normen und Richtlinien in Österreich, Frankreich, Kroatien, den USA, Serbien und der Schweiz dargestellt sind. Die in den untersuchten Dokumenten gegebenen Einflussparameter und Verfahren zur Ermittlung des Überblickfeldes werden detailliert beschrieben. Die Vielfalt der einzelnen Ansatzpunkte zur Bestimmung der Übersichtlichkeit wird hervorgehoben und Resultate von Untersuchungen an einem theoretischen Beispiel außerstädtischer einspuriger Kreisverkehrsführung werden erläutert.

Schlüsselwörter:

Kreisverkehr, Übersichtlichkeit, Regelwerke, Richtlinien, Normen, Überblickfeld

1. Introduction

An appropriate sight distance must be ensured on suburban roundabouts to enable a driver without the right of way to engage in the roundabout traffic flow in a safe manner, and to note on time the position of the vehicle in front of him. An appropriate sight distance is ensured by proper design of geometric elements of roundabouts.

In this paper, the focus is set on displaying key elements of the roundabout sight distance evaluation procedures described in Croatian guidelines, and in the roundabout-design guidelines, regulations, and standards as applied in Austria, France, USA, Serbia, and Switzerland.

Although Croatia has witnessed a significant increase in modern roundabout construction over the past decade, national regulations for their design have not as yet been prepared. Documents focusing on roundabout design issues in Croatia are *Guidelines for the design and equipment of roundabouts* [1] from 2002, and *Guidelines for the design of roundabouts on national roads* [2], from 2014, written for Hrvatske ceste d.o.o. The 2014 guidelines are mandatory for the design and planning of single-lane roundabouts on national roads.

In the aforementioned foreign countries with a long tradition in road construction, a developed road network, and a considerable number of roundabouts, these documents are written by permanent or temporary scientific-expert teams who, if needed, modify them in accordance with new scientific and expert knowledge. The documents are issued in form of guidelines (Austria [3], France [4] and USA [5]), regulations (Serbia [6]), and standards (Switzerland [7, 8]) and are implemented either as recommendations or mandatory documents.

Due to lack of national regulations, roundabout design in Croatia is usually carried out according to the aforementioned guidelines, but also based on German and Austrian guidelines, and Swiss standards [9]. Positive aspects of modern roundabouts are sometimes annulled because of such heterogeneous approach to the design of these intersections [9-12]. In order to provide much needed unambiguous instructions for the selection of design elements and roundabout performance checks, future national regulations should be based on the detailed study of all roundabout design parameters. At the moment, detailed studies are still being undertaken in order to define design elements (and their influence on the efficiency, level of service, and traffic safety) that could be used in the creation of this national document [13-15].

In order to gain a greater insight into the diversity of approaches for the evaluation of sight distances defined in aforementioned documents, influential parameters for determining the sight distance and the clear vision areas are presented in detail in this paper, and the sight distance analysis results are commented on by means of a theoretical example.

2. Sight distance evaluation methodology

While entering the roundabout the driver must pay attention to the left roundabout quadrant, in order to safely manoeuvre into a circulatory roadway [1-7, 16, 17]. At the same time, the driver on a circulatory roadway needs to have an adequate sight distance of the circulatory roadway in front of the vehicle (Figure 1) [1, 2, 5, 6, 16, 17]. For intersections with crosswalks, an additional check is required - analysis of the sight distance to the right (i.e. to the first next approach) [2, 3, 5]. Considering the fact that there are usually no crosswalks on suburban roundabouts, the evaluation of sight distance to the right was not included in this review.

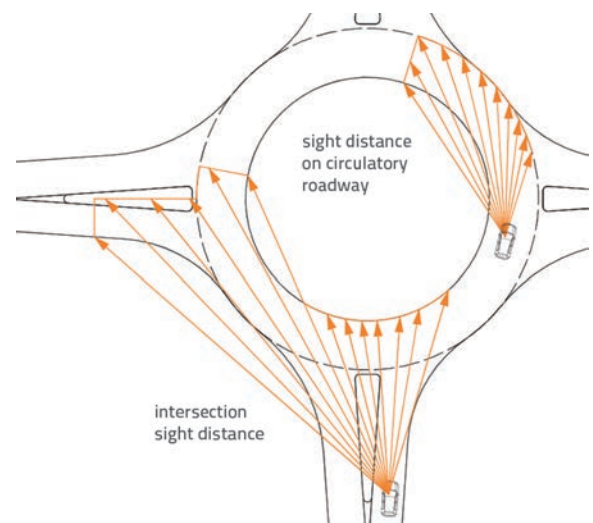


Figure 1. Sight distances on suburban roundabouts

On suburban roundabouts it is desirable to obstruct the driver's view of the opposing roundabout exit by elevating the central island [2, 3, 7, 16, 17]. In accordance with Croatian guidelines issued in 2014 [2], this is achieved by designing a dome like elevation at the centre of the circular island. In this way, the visibility of the central island is improved as well. The width of the circumferential belt of the roundabout central island is variable (depending on the visibility conditions), and amounts to no less than 2.0 m [2]. Absence of such a visibility obstruction can result in a greater entry speed, with certain vehicles driving into the central island or neglecting the right of way in the roundabout. At the same time, the central island needs to be designed in such a way that it does not impair visibility of drivers already moving within the circulatory roadway.

In the light of the above considerations, and contrary to traditional four-legged intersections where the sight distance analysis is based exclusively on defining a sight triangle (an area in which there should not be any obstacles that could prevent the driver from seeing and safely reacting to potentially conflicting vehicles) [18], the sight distance analysis on suburban roundabouts consists of:

- determining the intersection sight distance, and
- determining the sight distance on the circulatory roadway.

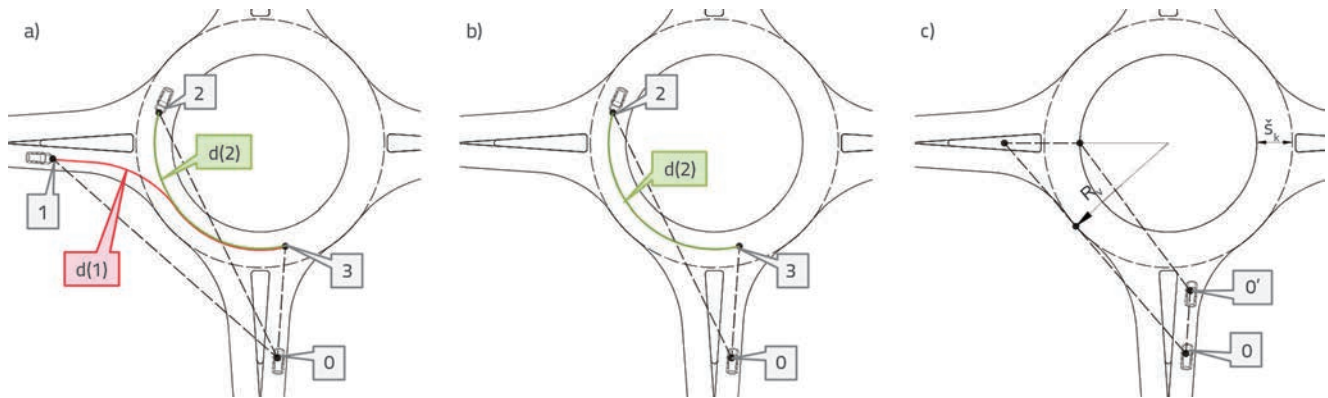


Figure 2. Intersection sight distance

2.1. Intersection sight distance

In accordance with the considered guidelines, regulations and standards, the required sight distance at the roundabout entry is achieved by providing for the sight triangle at every entry, i.e. the fields in which visibility obstacles are not allowed. As to the method for defining these fields, relevant documents can be grouped as follows (Figure 2):

- Group 1 (Figure 2.a), containing Austrian and American guidelines and Serbian regulations: the sight distance is defined based on a calculated (or set) path length of a vehicle with the right of way entering the roundabout from an adjacent left approach leg (vehicle 1, length $d(1)$) and a vehicle on the trajectory around the central island (vehicle 2, length $d(2)$), position of the driver's eye (point 0) and point of conflict of the considered traffic flow (point 3);
- Group 2 (Figure 2.b), containing Croatian guidelines and Swiss standards: the sight distance is defined based on a set path length of the vehicle with the right of way on the trajectory around the central island (vehicle 2, length $d(2)$), position of the driver's eye (point 0) and point of conflict of the considered traffic flow (point 3);
- Group 3 (Figure 2.c), containing French guidelines: the sight distance is defined based on the position of the driver's eye for two locations on the approach leg (point 0 and point 0'), outer radius of the roundabout (R_v) and circulatory roadway width (s_k).

2.1.1. Group 1

According to Austrian guidelines [3], path lengths of the vehicle with the right of way (vehicles 1 and 2, Figure 3) are invariable and independent of roundabout design elements and driving speed of these vehicles:

$$d(1) = d(2) = \text{const.} = 35 \text{ [m]} \quad (1)$$

Trajectories of vehicles with the right of way are located in the middle of the appropriate lane. The position of the driver's

eye (point 0), in regard to the layout, is located on the vehicle trajectory in the middle of the lane and offset for 3 m from the entrance (yield) line.

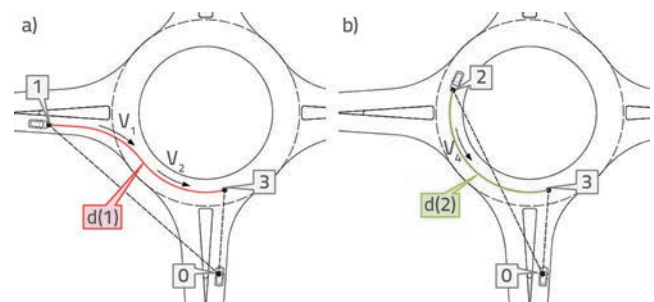


Figure 3. Vehicle path length: a) entering the roundabout from an adjacent left approach leg, b) on the circulatory roadway

The sight distance is inspected for the height of the driver's eye from 1 to 2.5 m and for obstacle height from 1 to 2 meters. Additionally, the entering stream of the sight triangle is limited to a distance of maximum 5 m from the entrance line at the adjacent left approach leg.

In accordance with American guidelines [5], path lengths of the vehicle with the right of way (vehicles 1 and 2) depend on the estimated vehicle speed (Figure 3), which is defined for the fastest vehicle path through the intersection. These lengths are calculated using the following formulas:

$$d(1) = 0,278 \cdot \left(\frac{V_1 + V_2}{2} \right) \cdot (t_c) \quad (2)$$

$$d(2) = 0,278 \cdot (V_4) \cdot (t_c) \quad (3)$$

where: $d(1)$ [m] - is the vehicle 1 path length, $d(2)$ [m] - is the vehicle 2 path length, V_1 [km/h] - is the vehicle 1 estimated entry speed, V_2 [km/h] - is the vehicle 1 estimated speed at the trajectory around the central island, V_4 [km/h] - is the vehicle 2 estimated speed at the trajectory around the central island, t_c [s] - critical headway for entering the major road (5 s).

The trajectory of the vehicle with the right of way is positioned in the middle of the lane. The driver's eye (point 0) is, with

regard to the layout, positioned on the vehicle trajectory in the middle of the lane, and offset for 15 m from the entrance line at roundabout entry. The sight distance is tested for the height of the driver's eye from 1.08 to 2.33 m, and the obstacle height from 1.08 m.

Similar to American guidelines, Serbian regulations [6] indicate that the path length of the vehicle with the right of way depends on the estimated vehicle speed (Figure 3), defined for the fastest vehicle path through the intersection. At the same time, Serbian regulations [6] take into consideration only the estimated entry speed of the vehicle (V_1) when defining the path length of vehicle 1. Furthermore, in accordance with the aforementioned regulations, the complexity of traffic activities in the roundabout requires provision of the so called inner visibility, where the length of the stopping sight distance (P_2) is considered the lower benchmark. The following expressions are used to calculate path lengths of the vehicle with the right of way:

$$d(1) = P_z(V_1) = \frac{t_r \cdot V_1}{3,6} + \frac{V_1^2}{254(f_t + w_k \pm i_n)} + \Delta L \quad (4)$$

$$d(2) = P_z(V_4) = \frac{t_r \cdot V_4}{3,6} + \frac{V_4^2}{254(f_t + w_k \pm i_n)} + \Delta L \quad (5)$$

where: P_z [m] - is the length of the stopping sight distance, V_1 [km/h] - is the vehicle 1 estimated entry speed, V_4 [km/h] - is the vehicle 2 estimated speed on the trajectory around the central island, t_r [s] - is the reaction time (1.5 s), w_k [-] - is the specific rolling resistance (0.012 - 0.020 for new pavements), i_n [-] - is the movement resistance from the longitudinal road slope, ΔL [m] - is the protective gap while stopping in front of an obstacle (5 - 10 m), f_t [-] - is the tangential friction factor, which depends on the estimated vehicle speed.

Trajectory of the vehicle with the right of way is offset for 1.5 m, respectively 2.0 m, from the roadway curb. The driver's eye (point O) is positioned on the vehicle trajectory offset for 1.5 m from the roadway curb and 15 m from the entrance line. The sight distance is analysed for the height of the driver's eye from 1.1 to 2.0 m, and for the obstacle height from 1.1 to 2.0 m.

2.1.2. Group 2

In accordance with Croatian guidelines issued in 2002 [1] (Table 1) and 2014 [2] (Table 2), all approaching drivers must be able to see the entire width of the roundabout. This is achieved by enabling the sight distance to the left (Figure 4.a) and forward sight distance at entry (Figure 4.b).

According to the 2002 Croatian guidelines [1], the sight distance to the left is dependent on the $d(2)$ length which is equal to the stopping sight distance of vehicle 2 moving through the roundabout at the speed of V_4 . This distance depends on the roundabout size; for medium single-lane roundabouts ($R_v = 20 - 30$ m) the length $d(2)$ is 40 m, and for medium double-lane roundabouts ($R_v = 30 - 45$ m) it is 50 m.

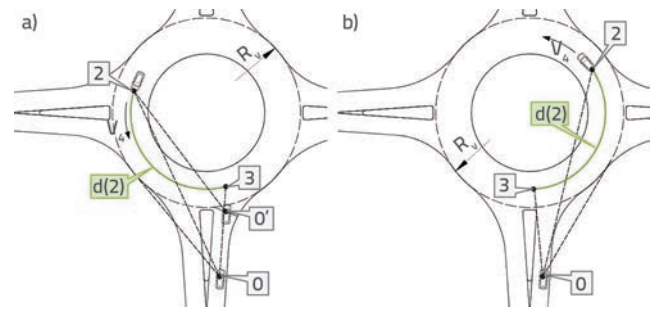


Figure 4. Croatian guidelines [1, 2]: a) sight distance to the left and b) forward sight distance at entry

While analysing sight distance to the left, the trajectory of the vehicle with the right of way is positioned in the middle of the circulatory lane. The eye of the driver (point O) is positioned, with regard to the layout, in the middle of the unexpanded lane (in case there are two entry lanes, it is positioned at the left lane) and offset for 15 meters from the entrance line. The sight distance to the left is analysed for the height of the driver's eye from 1.1 to 2.0 m, and for the obstacle height from 1.1 to 2.0 m.

The forward sight distance at entry, pursuant to the 2002 Croatian guidelines, is dependent on the $d(2)$ length which is determined on the basis of the design speed of the vehicle 2 moving through the roundabout (speed V_4): for the design speed of 40 km/h the recommended $d(2)$ length is 50 m, whereas the minimum is 40 m. Trajectory of the vehicle with the right of way is positioned in the middle of the circulatory lane. The position of the driver's eye (point O), with regard to the layout, is in the middle of the right lane, 15 m from the entrance line. The forward sight distance at entry is analysed for the height of the driver's eye from 1.1 to 2.0 m, and for the obstacle height from 0.1 to 2.0 m.

Table 1. Intersection sight distance according to 2002 Croatian guidelines [1]

Sight distance	Influential parameter	$d(2)$ [m]
Left	$d(2) = f(R_v)$	40
Forward	$d(2) = f(V_4)$	40 - 50

According to the 2014 Croatian guidelines [2], while analysing sight distance to the left, the $d(2)$ length must be greater than or equal to 40 m. With regard to the layout, the visibility obstacle is positioned in the middle of the circulatory lane, and the driver's eye in the middle of the stopping line (point O'). The procedure for constructing a stopping line at the roundabout lane entry is not described in the Guidelines. The Guidelines recommend an analysis of the sight distance to the left, which should be achieved by positioning the driver's eye in the middle of the unexpanded lane, 15 m from the stopping line (point O), but only on leg approaches with "high approach speeds". However, "high approach speeds" are not unambiguously defined. The sight distance to the left is analysed for the height of the driver's eye from 1.1 to 2.0 m, and the obstacle height of 2.0 m.

According to the 2014 Croatian guidelines, the forward sight distance at entry is defined by using the path length of the vehicle with the right of way $d(2)$, which should be greater than or equal to the length of the stopping sight distance P_z . The latter depends on the design speed of the vehicle with the right of way (speed V_d), which amounts to 40 km/h for medium suburban roundabouts ($R_v = 15 - 22.5$ m). The recommended stopping sight distance, which is to be used while checking visibility at roundabouts, amounts to 50 m. The minimum stopping sight distance given in the Guidelines is 35 m for the design speed of 40 km/h (this stopping distance corresponds to the value defined in the *Byelaw on basic traffic safety conditions to be met by rural public roads and their elements*, NN 110/01 [19]). The trajectory of the vehicle with the right of way is positioned in the middle of the circulatory lane. The driver's eye (point O) is positioned, in regard to the layout, in the middle of the lane at the distance of 15 m from the stopping line. The height of the driver's eye, in the forward sight distance at entry analysis, is 1.1 to 2.0 m. It can additionally be noted that the height of the object that should be seen by all drivers approaching the stopping line, at full width of the roundabout, from the distance equal to the stopping sight distance of no less than 40 meters, ranges from 0.25 to 2.0 m [2].

Table 2. Intersection sight distance according to 2014 Croatian guidelines [2]

Sight distance	Influential parameter	$d(2)$ [m]
Left	undefined	≥ 40
Forward	$d(2) = f(V_d)$	35 - 50

In accordance with the Swiss standard [7], the sight distance at roundabout entry is equal to the path length of the vehicle with the right of way circulating around the circulatory roadway $d(2)$. The trajectory of the vehicle with the right of way is positioned in the middle of the circulatory lane, and the $d(2)$ length is determined in accordance with the standard [8], which refers to the determination of sight distance on at-grade intersections (Figure 5). While determining the sight distance, the smallest roundabout deflection angle is applicable (β), as shown in Figure 5 and Table 3.

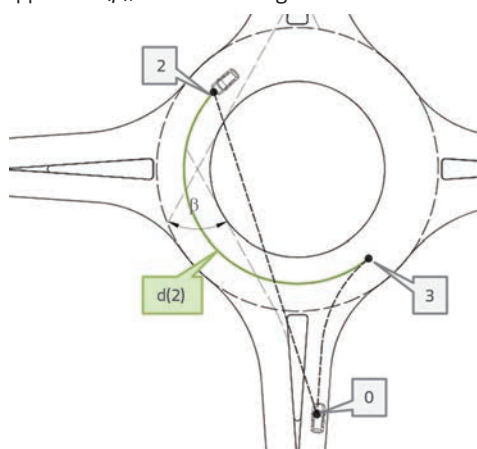


Figure 5. Deflection angle and sight distance [7]

Table 3. Relationship between sight distance and deflection angle [7]

β [°]	$d(2)$ [m]
< 18	35 (50)
18 - 40.5	/
> 40.5	20 (35)

Two sight distances are given for a certain value of deflection angle: the smaller one shows the length of the stopping sight distance, and the greater the sight distance that must be ensured at intersections under special conditions (for example at great longitudinal slopes). The value that corresponds the best to the intersection's position in the traffic network, to its road rank, and number of lanes, is chosen. At the same time, in accordance with the standard [8], the eye of the driver (point O) is positioned on the vehicle trajectory in the axis lane and offset for 5 meters from the entrance line.

2.1.3. Group 3

According to French guidelines [4], the clear vision area at roundabout entry is defined with the elements shown in Figure 6:

- with a straight through point O (shows the position of the driver's eye at the distance of approximately 14 to 15 meters from the entrance line, and 2 meters from the curb), which is tangential to the outer radius of the roundabout (R_u) and
- with a straight through point O' (shows the position of the driver's eye at the distance of 4 meters from the entrance line, and 2 meters from the curb), which is tangential to the circle concentric with the central island curb, while the radius of that circle is at least 2 meters smaller than the radius of the central island (R_v).

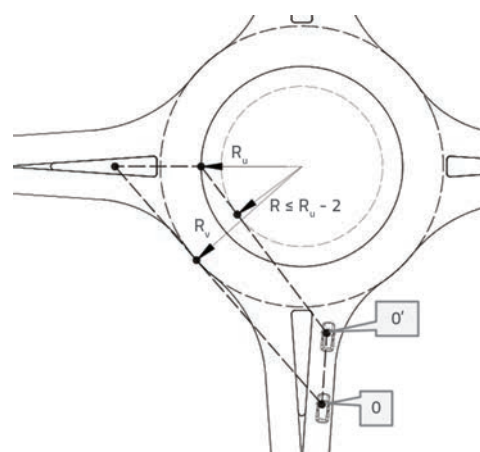


Figure 6. Construction of clear vision area [4]

The driver's eye position is set to maximum 15 m from the entrance line because, according to these guidelines, too much visibility to the left can be harmful to the intersection's safety: drivers approaching the roundabout may focus their attention

only on the open spots on the entrance directly to their left, while neglecting other movements on the circulatory roadway [4].

2.2. Sight distance on circulatory roadway

Depending on the way the visibility field is defined, the considered guidelines, regulations and standards can be divided into the following groups (Figure 7):

- Group 1 (Figure 7.a), containing American and Croatian guidelines and Serbian regulations: the sight distance is defined based on the calculated or set trajectory-length values for a vehicle moving along a circulatory lane (vehicle 0, length d), position of the driver's eye (point O) and obstacle position (point 4);
- Group 2 (Figure 7.b), containing Austrian and French guidelines and Swiss standards: the analysis of sight distance on the circulatory roadway is not described, but guidelines for the central island design are given, i.e. for installation of visibility obstacles within the central island.

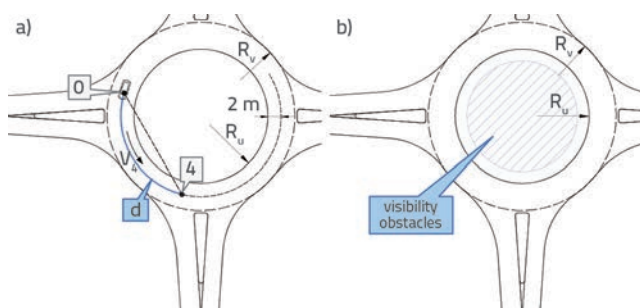


Figure 7. Sight distance on circulatory roadway: a) Group 1 and b) Group 2

2.2.1. Group 1

In accordance with American guidelines [5], Serbian regulations [6] and Croatian guidelines from 2002 [1] and 2014 [2], the sight distance on the circulatory roadway depends on the stopping distance of the vehicle moving along the circulatory lane (d), position of the driver's eye (O) and the obstacle (4). The length of the path is measured along the trajectory of the vehicle offset 2 meters from the curb of the central island, i.e. in the layout, the driver's eye and the obstacle are offset for 2 meters from the curb of the central island (Figure 7.a).

According to American guidelines [5], the length (d) is equal to the vehicle stopping distance, in regard to the speed at the circulatory lane (speed V_4), which is calculated in accordance with the expression:

$$d = 0,278 \cdot t \cdot V_4 + 0,039 \cdot \frac{V_4^2}{a} \quad (6)$$

where t [s] - is the reaction time (2.5 s), V_4 [km/h] - is the vehicle speed at the circulatory roadway, and a [m/s^2] - is the deceleration of the vehicle ($3.5 m/s^2$). The sight distance is

analysed for the height of the driver's eye from 1.08 to 2.33 m, and for obstacle height of 0.6 m.

In accordance with Serbian regulations [6], vehicles driving along the circulatory roadway must have an unobstructed view of the vehicle in front, as well as the possibility of perceiving a low obstacle at the circulatory roadway. The path length (d) is equal to the length of the stopping sight distance (P_z) for the speed in the circulatory lane (V_4), determined in accordance with the expression:

$$d = P_z (V_4) = \frac{t_r \cdot V_4}{3,6} + \frac{V_4^2}{254(f_t + w_k \pm i_n)} + \Delta L \quad (7)$$

where: P_z [m] - is the stopping sight distance, V_4 [km/h] - is the vehicle 2 estimated speed on the trajectory around the central island, t_r [s] - is the reaction time (1.5 s), w_k [-] - is the specific rolling resistance (0.012 - 0.020 for new pavements), i_n [-] - is the movement resistance from the longitudinal road slope, ΔL [m] - is the protective gap while stopping in front of an obstacle (5 - 10 m), f_t [-] - is the tangential friction factor, which depends on the estimated vehicle speed.

The sight distance is analysed for the driver's eye height from 1.1 to 2.0 m, and for the obstacle height varying from 0.2 to 2.0 m. According to the 2002 Croatian guidelines [1], the sight distance depends on the size of the outer radius of the roundabout ($d = 50$ m for $R_v = 30 - 45$ m; $d = 40$ m for $R_v = 20 - 30$ m), and on the vehicle operating speed in the roundabout (for the speed of 40 km/h, the recommended sight distance is 50 m, while 40 m is the minimum). The sight distance is analysed for the driver's eye height from 1.1 to 2.0 m, and for the obstacle height from 0.1 to 2.0 m.

According to the 2014 Croatian guidelines [2], the length d should be greater than or equal to 40 m. When analysing visibility in the roundabout, the driver's eye height ranges from 1.1 to 2.0 m, and the obstacle must be visible from the height ranging from 0.1 m to 2.0 m.

2.2.2. Group 2

The procedure for analysing the sight distance on the circulatory roadway is not described in Austrian [3] and French guidelines [4] and in the Swiss standard [7]. However, it is noted that the clarity of the roundabout in the traffic network should be ensured by designing a visibility obstacle, especially on suburban roads.

According to Austrian guidelines [3], a central island should be designed on roundabouts with the outer radius greater than 17.5 meters, so that the driver entering the intersection has an obstructed view of the opposing exit. High shrubbery or similar visibility obstacles should be located at the centre of the island, so that they do not interfere with the clear vision area of the driver entering the roundabout.

In the case of French guidelines [4], the central island must not contain visibility obstacles (for example high shrubbery) at distances of less than 2 m from the curb (2.5 m from the entrance line if there is no curb).

It is indicated in the Swiss standard [7] that a clear vision area extending over the entire central island can instigate drivers entering the roundabout to neglect the right of way of vehicles that are already driving through the roundabout. For this reason, and to ensure the visibility of the roundabout in the traffic network as well, it is necessary to limit the sight distance over the central island by planting vegetation or installing traffic equipment. At the same time, the intersection sight distance and stopping sight distance must not be compromised.

3. Sight distance analysis and results

The sight distance analysis was conducted on a theoretical example of a four-legged single-lane roundabout in order to display diversity of approaches to the evaluation of sight distances and resulting clear vision areas, as contained in the considered guidelines, norms and regulations. Basic design elements used for this roundabout were:

- outer radius (R_v) of 20 meters,
- circulatory roadway width (s_k) of 6 meters, and
- approach leg axes that intersected at the centre of the central island, at an angle of 90° .

These are the average dimensions of the aforementioned basic design elements given in Croatian guidelines [2] for this type of intersection.

3.1. Input parameters

Tables 4 and 5 show input parameters used for the intersection sight distance analysis and the analysis of sight distance on circulatory roadways. Input parameters are shown in Figure 8:

- a: distance of the driver's eye from the entrance line
- b: distance of the driver's eye from the right curb of the roadway
- s: approach lane width

- c: distance of vehicle 0 trajectory, circling around the circulatory roadway, from the curb of the central island
- s_k : circulatory lane width
- c(1): distance of vehicle 1 entering the intersection from the adjacent left approach leg from the roadway curb
- c(2): distance of vehicle 2 circling around the circulatory roadway from the curb of the central island
- h(0): height of the driver's eye
- h(1): obstacle height
- d(1): path length of vehicle 1 entering the roundabout from the adjacent left approach leg
- d(2): path length of vehicle 2 circling around the circulatory roadway
- d: path length of vehicle 0 circling around the circulatory roadway.

The following driving speed of vehicles with the right of way was adopted for the purposes of this analysis (Figure 8):

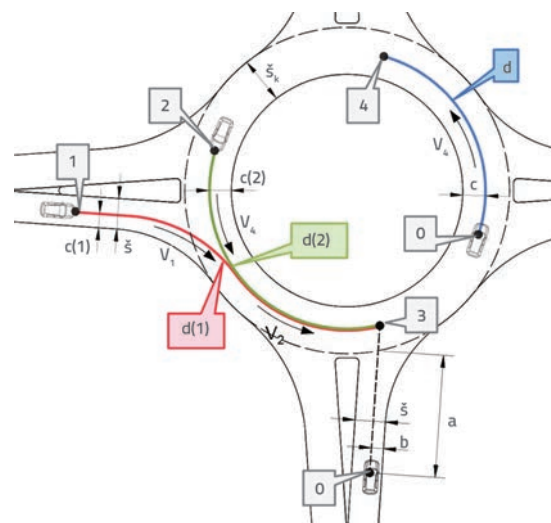


Figure 8. Sight distance analysis parameters

Table 4. Intersection sight distance analysis parameters

Država		a [m]	b [m]	c(1) [m]	c(2) [m]	h(0) [m]	h(1) [m]	d(1) [m]	d(2) [m]
Austria		3	$\check{s}/2$	$\check{s}/2$	$\check{s}_k/2$	1.0 - 2.5	1.0 - 2.0	≤ 35	35
USA		15	$\check{s}/2$	$\check{s}/2$	$\check{s}_k/2$	1.08 - 2.33	1.08	$f(V_1, V_2)$	$f(V_4)$
Serbia		15	1.5	1.5	2.0	1.1 - 2.0	1.1 - 2.0	$f(V_1)$	$f(V_4)$
Croatia (2002.)	left	15	$\check{s}/2$	-	$\check{s}_k/2$	1.1 - 2.0	1.1 - 2.0	-	40
	forward	15	$\check{s}/2$	-	$\check{s}_k/2$	1.1 - 2.0	0.1 - 2.0	-	40 - 50
Croatia (2014.)	left	15	$\check{s}/2$	-	$\check{s}_k/2$	1.1 - 2.0	1.1 - 2.0	-	≥ 40
	middle of the stopping line			-	$\check{s}_k/2$	1.1 - 2.0	1.1 - 2.0	-	≥ 40
forward	15	$\check{s}/2$	-	$\check{s}_k/2$	1.1 - 2.0	0.1 - 2.0	-	35 - 50	
Switzerland		5	$\check{s}/2$	-	$\check{s}_k/2$	1.0 - 3.0	1.0 - 3.0	-	20 - 35
France		15	2.0	-	-	1.0	1.0	-	-
			2.0	-	-	1.0	1.0	-	-

- default speed of the vehicle with the right of way entering the roundabout from an adjacent left approach leg is 40 km/h (vehicle 1: speed V_1) [2, 5, 6],
- default speed of the vehicle with the right of way circling on the circulatory roadway because of the curvature of the vehicle trajectory around the central island is 25 km/h (vehicle 1: speed V_2 ; vehicle 2 and vehicle 0: speed V_4) [2, 5, 6, 20, 21].

Table 5. Sight distance analysis parameters for circulatory roadways

State	c [m]	h(0) [m]	h(1) [m]	d [m]
Austria	-	-	-	-
USA	2	1.08 - 2.33	0.6	$f(V_4)$
Serbia	2	1.1 - 2.0	0.2 - 2.0	$f(V_4)$
Croatia (2002.)	2	1.1 - 2.0	0.1 - 2.0	40 - 50
Croatia (2014.)	2	1.1 - 2.0	0.1 - 2.0	≥ 40
Switzerland	-	-	-	-
France	-	-	-	-

3.2. Analysis results

Vehicle path lengths applied, and the resulting clear vision areas, are shown in Figure 9. The line of sight towards the opposing exit from the intersection is also shown in this figure (marked with an orange arrow). According to the analysed documents, this line should be interfered with on suburban roundabouts by placing visibility obstacles within the central island. Length limitation of the left arm of the sight triangle at 5 m from the junction entry, defined by Austrian guidelines [3], resulted in the length $d(1)$ of 33.9 m, while for the $d(2)$ the length of 35 meters was adopted (Figure 9.a). The clear vision area at roundabout entry, constructed in accordance with instructions from French guidelines [4], is shown in Figure 9.b. According to the 2014 Croatian guidelines [2], the smallest recommended sight distance to the left and on the circulatory roadway ($d(2)$ and d) is 40 meters, while the length applied for forward sight distance at entry analysis ($d(2)$) amounts to 50 m (Figure 9.c). Assuming that the driving speed of the vehicle with the right of way amounts to $V_1 = 40$ km/h and $V_2 = V_4 = 25$ km/h [20, 21], and the zero percent longitudinal slope in the intersection zone, the sight distances defined in accordance with American guidelines amount to $d(1) = 45.2$ m, $d(2) = 34.8$ m, and $d = 24.6$ m (Figure 9.d) [5], while according to Serbian regulations [6] they amount to $d(1) = 40.6$ m and $d(2) = d = 25.3$ m (Figure 9.e). Due to a large deflection angle of the considered intersection ($\beta = 69^\circ$), the applied length $d(2)$ is 20 meters (Figure 9.f) [7, 8] when the clear vision area is defined according to Swiss standards. The resulting total surfaces of clear vision areas, defined for the required intersection sight distance on one roundabout

approach, and for the required sight distance on the circulatory roadway, are shown in Figure 9 and in Table 6. As shown in Figure 9, the greatest clear vision area for the required sight distance on a circulatory roadway is recommended by Croatian guidelines from 2014 (432 m²) [2]. The smallest clear vision area for the required sight distance on a circulatory roadway is the one defined by American guidelines (194 m²) [5]. Compared to other analysed documents, the instructions for construction of clear vision areas given in Croatian guidelines result in up to 35 - 86 % larger total clear vision areas. This is due to the fact that Croatian guidelines prescribe one additional sight distance check: evaluation of the forward sight distance at entry (Figure 9.c). The area of the forward sight distance at entry defined according to the instructions given in [2] is 635 m², while the area of sight distance to the left is 360 m².

Table 6. Total clear vision areas for analysed intersection sight distances

State	Austria	France	Croatia	USA	Serbia	Switzerland
Area [m ²]	314	317	995	642	484	144

The analysis results show that, along with the set input parameters, the smallest distance from the curb of the central island on which visibility obstacles can be placed significantly varies between the documents (Table 7). The longest distance is defined by the area of forward sight distance at entry determined by the 2014 Croatian guidelines [2] (12 m), and the smallest one is defined for the intersection sight distance in accordance with Swiss standards [7, 8] (0 m). Instructions for the placement of visibility obstacles given in Croatian guidelines result in up to 63 - 100 % larger distances from the curb of the central island, compared to other analysed documents.

Table 7. The minimum distance of visibility obstacles from central island curb

State	Austria	France	Croatia	USA	Serbia	Switzerland
Minimum distance [m]	4.51	2.76	12.04	3.26	3.50	0.00

These significant discrepancies are the direct result of differences in the sight distance analyses approach between the analysed documents, and different path lengths of vehicles with the right of way (20 - 50 m). The fulfilment of design requirements for the central island, i.e. interference of the line of sight towards the opposite exit of a suburban roundabout, can be analysed by defining clear vision areas. As shown in Figure 9, the requirement for line interference is met in fields defined according to Austrian, American and French guidelines, Serbian regulations, and Swiss norms. The resulting clear vision areas defined in accordance with Austrian and French guidelines, and in Swiss standards, fulfil the central

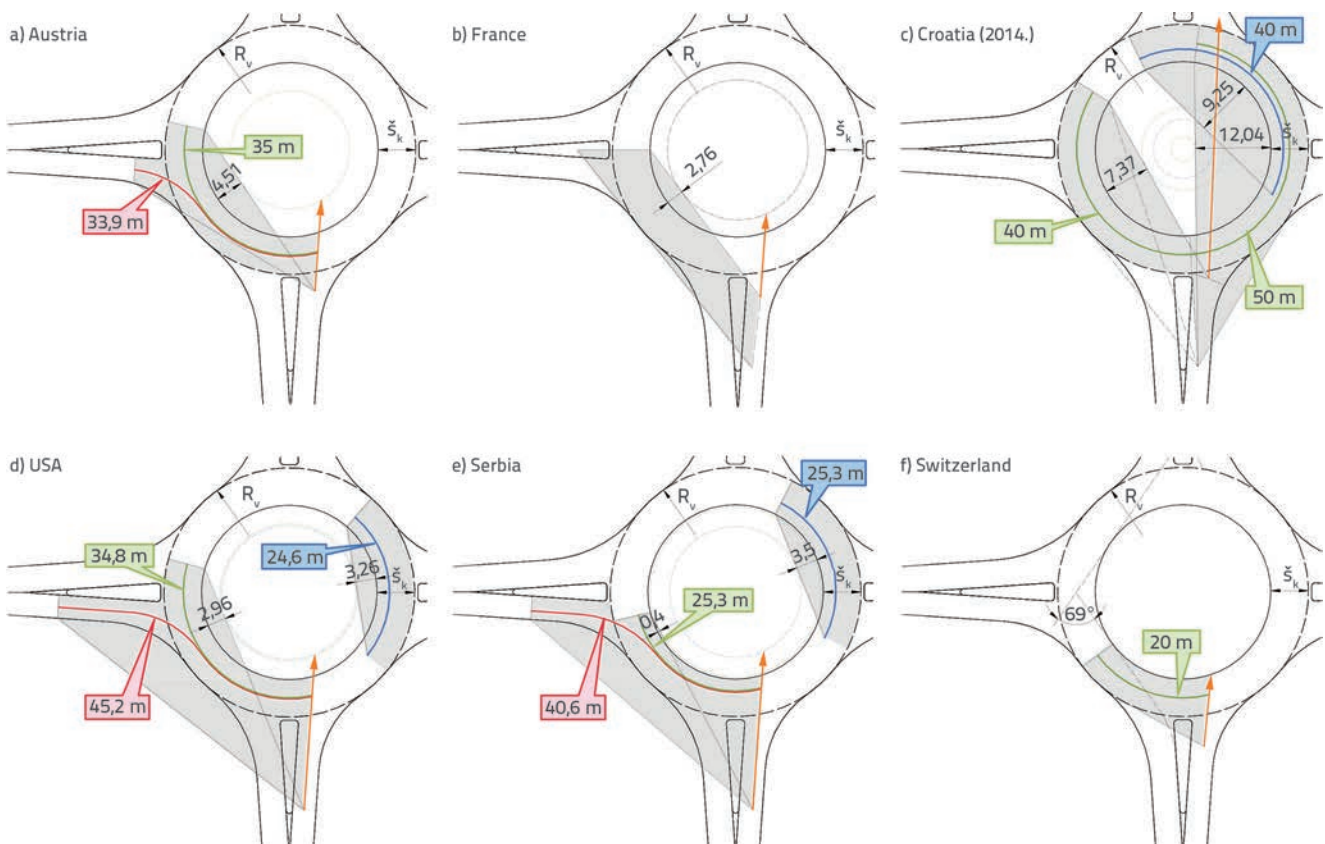


Figure 9. Clear vision areas on a single-lane suburban roundabout ($R_v = 20$ m, $s_k = 6$ m)

island design requirements described in Chapter 2.2.2. Clear vision areas defined in accordance with American guidelines and Serbian regulations enable placing visibility obstacles within the central island (Figure 9d and 9e).

The requirement for obstructing the line of sight towards the opposing intersection exit is not fulfilled with the clear vision area defined in the 2014 Croatian guidelines. According to these guidelines, the central island may contain visibility obstacles only at a distance greater than 12.04 m from the curb, in order to ensure the required forward sight distance at entry (Figure 9.c). At that, the correct design of the central island is disabled, i.e. the line of sight towards the opposing exit is disrupted by placing visibility obstacles within the central island. This problem becomes insignificant by increasing the outer radius of single-lane roundabouts.

4. Conclusion

An overview of roundabout design regulations, standards and guidelines applied in Austria, France, Croatia, USA, Serbia and Switzerland is given in this paper. While analysing the intersection sight distance, most of these documents take into consideration exclusively the sight distance at the circulatory roadway width, i.e. visibility towards the vehicle with the right of way which circles around the central island. Austrian and American guidelines, and Serbian regulations, analyse visibility towards the vehicle with the right of way approaching the junction from the adjacent left

approach leg. At the same time, the roundabout sight distance analysis approach, described in American guidelines and Serbian regulations, is based on calculation of the stopping sight distance of the vehicle with the right of way, which requires definition of the vehicle speed on the trajectory through the roundabout. Such an approach gives the stopping sight distance values in accordance with the expected speed profile at intersection (dependent on the applied roundabout design elements).

According to American and Croatian guidelines, and as per Serbian regulations, the determination on the vehicle speed on the trajectory through the intersection (the so called fastest path vehicle speed - highest theoretical speed through the roundabout) is an indispensable part of performance check in roundabout design. Unlike American guidelines and Serbian regulations, Croatian guidelines do not use this fastest path vehicle speed in the sight distance analysis. This can lead to over-dimensioned sight distances and clear vision areas, especially when analysing sight distance on a circulatory roadway, and ultimately to non-compliance with requirements concerning obstruction of the line of sight towards the opposing suburban roundabout exit. In regard to the aforementioned and the fact that the clear vision area for forward sight distance at entry (defined only in Croatian guidelines) greatly overlaps with the clear vision area that must be ensured for the drivers moving through the circulatory roadway, the issue of validity of performing such an analysis on single-lane suburban roundabouts, by applying the input parameter value recommended by the new Croatian guidelines, may be raised.

REFERENCES

- [1] Dadić, I., Tollazzi, T., Legac, I., Čičak, M., Marić, V., Kos, G., Brlek, P.: Smjernice za projektiranje i opremanje raskrižja kružnog oblika – rotora, Hrvatske ceste d.o.o., Zagreb, 2002.
- [2] Deluka-Tibljaš, A., Tollazzi, T., Barišić, I., Babić, S., Šurdonja, S., Renčelj, M., Pranjić, I.: Smjernice za projektiranje kružnih raskrižja na državnim cestama, Hrvatske ceste d.o.o., Zagreb, 2014.
- [3] Plangleiche Knoten – Kreisverkehre, Österreichische Forschungsgesellschaft Straße-Schiene-Verkehr (FSV), (RVS 03.05.14), Wien, 2010.
- [4] Aménagement des carrefours interurbains sur les routes principales, Carrefours plans – guide technique, Service d'Etudes Techniques des Routes et Autoroutes, Centre de la Sécurité et des Techniques Routières, Bagnex Cedex, France, 1998.
- [5] NHCRP, Report 672: Roundabouts: An Informational Guide, Second Edition, Federal Highway Administration, Transportation Research Board: Washington, 2010.
- [6] Pravilnik o uslovima koje sa aspekta bezbednosti saobraćaja moraju da ispunjavaju putni objekti i drugi elementi javnog puta, Službeni glasnik RS, 50/2011.
- [7] Knoten, Knoten mit Kreisverkehr, Vereinigung Schweizerischer Strassenfachleute (VSS), Schweizer Norm (SN 640 263), Zürich, 2000.
- [8] Knoten; Sichtverhältnisse in Knoten in einer Ebene, Vereinigung Schweizerischer Strassenfachleute (VSS), Schweizer Norm (SN 640 273), Zürich, 2010.
- [9] Stančerić, I., Dobrica, T., Ahac, S., Dragčević, V., Tenžera, D.: Offtracking control requirements for quality roundabout design, *Road and Rail Infrastructure III, Proceedings of the Conference CETRA 2014*, Split, pp. 263–268, 2014.
- [10] Barišić, I., Jurković, S., Tollazzi, T.: Enclosure to roundabouts use improvement in the Republic of Croatia, *The Fourth Croatian Road Congress*, Cavtat, pp. 1–8, 2007.
- [11] Legac, I., Pilko, H., Šubić, N.: Introduction of Roundabouts in Croatia – preliminary experiences, *16th IRF World Congress*, Lisboa, pp. 9, 2010.
- [12] Legac, I., Pilko, H., Banović, I.: Neka iskustva s uvođenjem kružnih raskrižja u Hrvatskoj/Požegi, Radovi Zavoda za znanstveni i umjetnički rad u Požegi, 1, pp. 259–272, 2012.
- [13] Zirkel, B., Park, S., McFadden, J., McCarthy, L., Angelastro, M.: An Operational Analysis of Modern Roundabouts in the United States, *IMSA Journal* (September/October 2012), pp. 37–47, 2012.
- [14] Mussone, L.: The analysis of roundabouts through visibility, *Procedia - Social and Behavioral Sciences*, 87 (2013), pp. 250–268
- [15] Pilko, H., Brčić, D., Šubić, N.: Study of vehicle speed in the design of roundabouts, *GRAĐEVINAR*, 66 (2014) 5, pp. 407–416, 2014.
- [16] Pratelli, A., Souleyrette, R. R.: Visibility, Perception and Roundabout Safety, *Urban Transport XIV*, pp. 577–588, 2009., <http://dx.doi.org/10.2495/ut090511>
- [17] Pratelli, A., Souleyrette, R.R., Harding, C.: Roundabout perception: review of standards and guidelines for advanced warning, *Urban Transport XVI*, pp. 71–82, 2010.
- [18] Cvitanić, D., Vujašinović, A., Stazić, T.: Preglednost cestovnih raskrižja u razini, *GRAĐEVINAR*, 63 (2011) 9/10, pp. 859–868.
- [19] Pravilnik o osnovnim uvjetima kojima javne ceste izvan naselja i njihovi elementi moraju udovoljavati sa stanovišta sigurnosti prometa, NN 110/01
- [20] Fernandes, P., Salamati, K., Roupail, N.M., Coelho, M.C.: Identification of emission hotspots in roundabouts corridors, *Transportation Research Part D*, 37 (2015), pp. 48–64, <http://dx.doi.org/10.1016/j.trd.2015.04.026>
- [21] NHCRP, Report FHWA-RD-00-067: Roundabouts: An Informational Guide, Federal Highway Administration, Transportation Research Board, Washington, 2000.