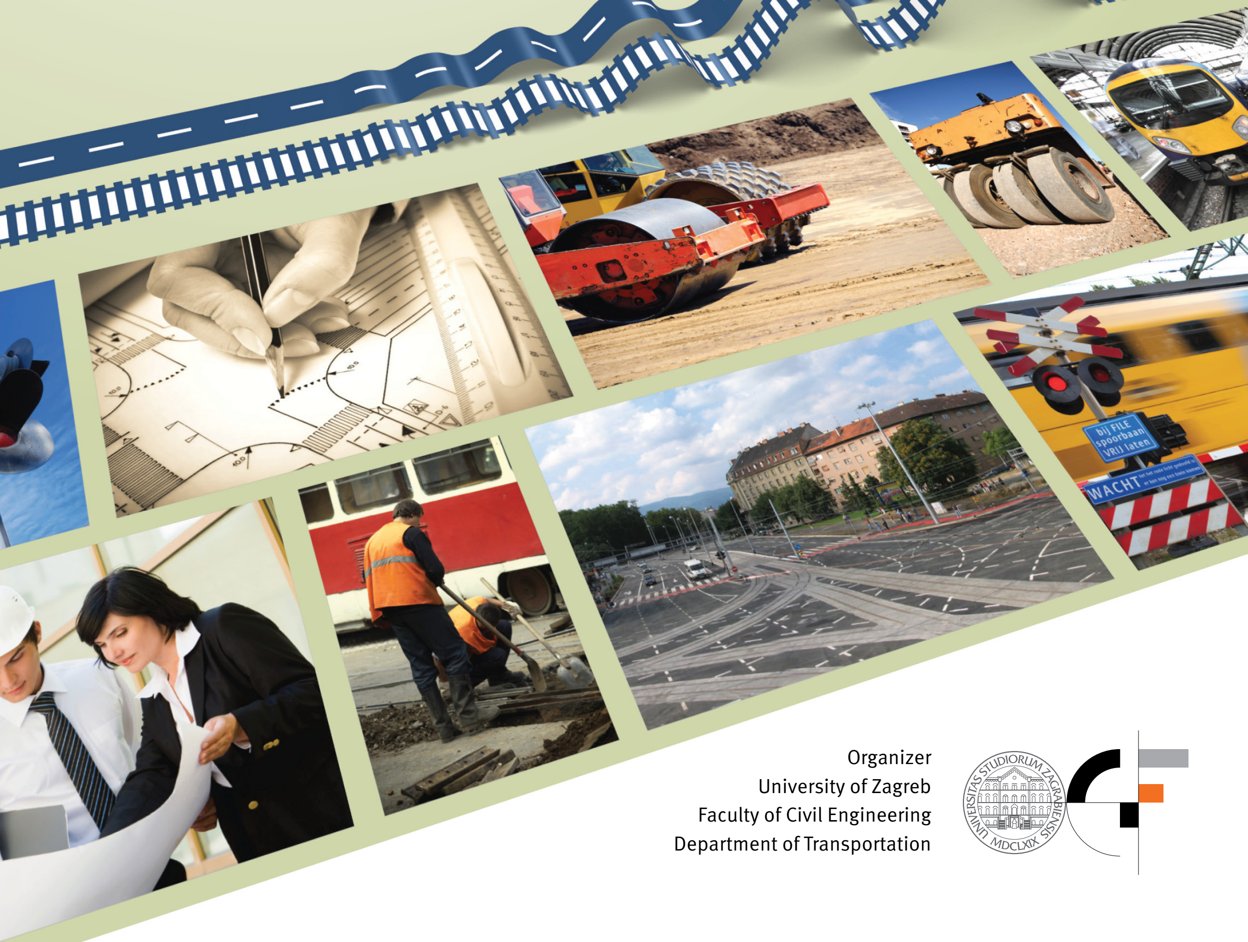
CETRA 2012

2nd International Conference on Road and Rail Infrastructure
7–9 May 2012, Dubrovnik, Croatia

Road and Rail Infrastructure II

Stjepan Lakušić – EDITOR



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Road and Rail Infrastructure II

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CETRA[2012]
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FOREWORD

The 2nd International Conference on Road and Rail Infrastructure – CETRA 2012 was organized by the University of Zagreb – Faculty of Civil Engineering, Department of Transportation. The Conference is held in Dubrovnik, Croatia. Dubrovnik is the "pearl of the Adriatic coast" and well known phrase related to it states "Those who seek paradise on Earth should come to Dubrovnik and see Dubrovnik". The First International Conference on Road and Rail Infrastructure – CETRA 2010 is held in Opatija, Croatia. Great interest of participants in topics from the field of road and rail infrastructure during the conference CETRA 2010 in Opatija, where 140 presentations of papers from 29 countries took place, confirmed the soundness of Department for Transportation Engineering's decision on organizing such international event. Positive comments of the participants after the past Conference motivated the Department for Transportation Engineering, Faculty of Civil Engineering at University of Zagreb to continue the organization of such an event in the upcoming years (on a biennial basis).
In the year 2012, 2nd International Conference on Road and Rail Infrastructure – CETRA 2012 has been organized, with the intention of bringing together scientists and experts in the fields of road and railway engineering, giving them another opportunity to present the results of their researches, findings and innovations. Road and railway infrastructure is closely related, but scientific and professional gatherings covering both fields simultaneously are rarely being organized. The growing volume of traffic, both passenger and cargo, demands not only the development of the vehicles themselves (increasing their cargo capacity and speed), but also the timely construction and regular maintenance of infrastructure. It is exactly for this reason that the 2nd International Conference on Road and Rail Infrastructure – CETRA 2012 covers many areas: traffic planning & modelling, infrastructure projects, design of road and rail substructure and superstructure, construction and maintenance process, structural monitoring, urban transport infrastructures, application of recycled materials, innovation and new technology, environmental protection – noise and vibrations and, above all, education, which today has an increasingly important role.
This second Conference CETRA 2012 attracted a large number of papers from 39 countries and 52 Universities. More than 142 papers were presented at the Conference and are contained in these proceedings Road and Rail Infrastructure II. The papers are divided into the following sections: Education, Traffic planning and modelling, Infrastructure projects, Infrastructure management, Road infrastructure planning, Road pavement, Road maintenance, Structures and structural monitoring, Innovation and new technologies, Design of road and railways, Rail track structure, Environmental, Geotechnics, Integrated timetables, Urban transport planning and modelling, Urban transport infrastructure, Vehicles, Traffic safety.
The organizers of the Conference express their thanks to all Businesses and Institutions who helped in organization of this Conference. The Editor is grateful to all the authors for the excellent papers contributed to this book and wishes to thank the members of the International Academic Scientific Committee who participated in the review process. Our gratitude also goes to all the participants for their willingness to come to Dubrovnik and take part in CETRA 2012.

THE EDITOR

Prof. dr. Stjepan Lakušić
May, 2012.

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CONTENTS

4 INFRASTRUCTURE MANAGEMENT

5 ROAD INFRASTRUCTURE PLANNING

6 ROAD PAVEMENT

13 GEOTECHNICS

14 INTEGRATED TIMETABLES

15 URBAN TRANSPORT PLANNING AND MODELLING

SPEED AS AN ELEMENT FOR DESIGNING ROUNDABOUTS

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Abstract

The increasing construction and implementation of roundabouts in the last 20 years is a result of a need for capacity increment, as well as the safety level increment on road intersections at-grade. Designing and shaping roundabouts, especially in urban areas, represents a complicated problem with a number of different conditioned elements that need to be satisfied. Geometrical elements such as the dimension of the outer roundabout diameter and number and width of the lanes considerably affect the trajectory of the vehicle's path through the intersection, respectively the vehicle speed that has an immediate effect on the safety and the capacity of the roundabout. Through a depiction of four existing roundabouts in the City of Zagreb, this paper will analyze the speed as an important roundabout designing factor. The research results will provide guidelines for roundabout designers, considering that the design speed is in correlation with the measured actual vehicle speed on a roundabout.

Keywords: roundabouts in urban areas, modelling and designing,
vehicle movement trajectory vehicle speed

1 Introduction

Modelling and designing roundabouts with small diameters (Dv ≤ 35m) in urban areas, presents a complicated task where a series of conditioned elements must be satisfied. Geometrical elements such as the inscribed circle radius and the number and width of the approaching lanes considerably affect the shape of vehicle movement trajectory through the intersection, i.e. the speed of the vehicles that has direct impact on the roundabout safety and capacity. A well-designed roundabout reduces the relative speeds between conflicting traffic streams by requiring vehicles to negotiate the roundabout along a curved path. Therefore, the ability to predict the vehicular speeds through the roundabout in the preliminary design is an important element while designing and modelling roundabouts. This paper will show an analysis of four roundabouts in the City of Zagreb, as well as the predicted speed on the roundabout entrance, circulatory roadway and exit in relation with the actual measured speeds of the analyzed intersections.

2 The speed on the vehicle path through roundabout

2.1 Design speed

Achieving the adequate speed throughout the roundabout results in accident possibility decrement, and also in intersection capacity increment. With the increment of the trajectory curve, the speed between the vehicles entering the circulatory roadway decreases as well as the speed of the vehicles already in the roundabout. Thus, the number of traffic accidents that happen while entering or exiting the circulatory roadway considerably decrease. However, on roundabouts with multilane roundabouts (on circular roadways and approach legs) increasing vehicle path curvature creates greater side friction between adjacent traffic. This could result in traffic accident increment caused by the interlacing of vehicles or their overrunning the roadway [6]. Therefore, with the goal of decreasing traffic accidents for every roundabout type an optimum design speed is suggested (Figure 1) [6].

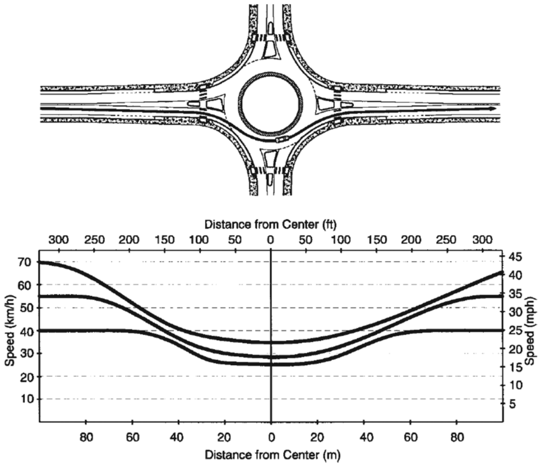


Figure 1 Depiction of the design speed values for a single-lane roundabout [6]

Table 1 shows maximum recommended values of the design speed for a vehicle entering a roundabout.

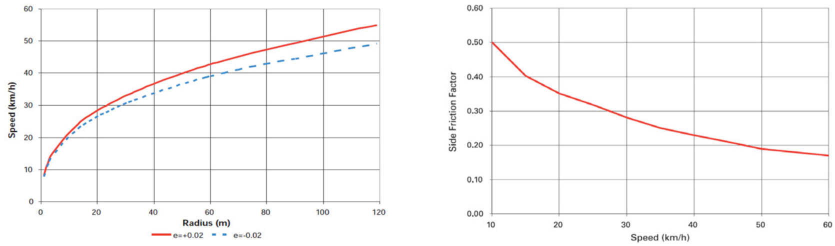
Table 1 Maximum recommended design speed for a vehicle entering a roundabout [2, 6]

Roundabout type	**Maximum recommended design speed at the roundabout entrance [km/h]**
Mini roundabout (RKT_m)	25 [km/h]
Small, single-lane (1) roundabout (RKT_M)	35 [km/h]
Small, double-lane (2) roundabout (RKT_M)	40 [km/h]
Medium, single-lane (RKTSV)	40 [km/h]
Medium, double-lane (RKTSV.2)	50 [km/h]

Calculating the design speed is based on the radii of the vehicle path as shown:

$$V = \sqrt{127R(e+f)} \tag{1}$$

where: V = design speed [km/h], R = radius [m] , e = superelevation rate [m/m], f = side friction factor [6].
Adherence between the pneumatic and the roadway is important for the stability and the safety of the vehicle movement through the roundabout, i.e. for the safer negotiation of the vehicle path. Superelevation values are usually assumed to be +0.02 for entry and exit curves and -0.02 for curves around the central island. Values of the side friction factor depend on the vehicle speed, the roadway type and the condition of the roadway (Figure 2.).
The design speed shouldn't differ considerably from the actual roundabout speed, and should be in correlation with other design parameters, respectively with the presumed traffic environment [4, 6].



a) vehicle speed and diameter relation b) side friction factor and vehicle speed relation

Figure 2 Relation depiction; a) diameter of the vehicle path and vehicle speed b) vehicle speed and side friction factor [6]

2.2 Vehicle path through the roundabout

For determining the speed on the roundabout, it is necessary to determine the fastest vehicle path allowed by the geometry (the trajectory that allows the maximum vehicle speed through the roundabout). While determining the vehicle path it is assumed that there is no other traffic or marked traffic lanes. Therefore, the vehicle can move freely through the approach leg, the approach entrance, around the central island, and towards the exit. It can be noticed that every vehicle path is characterized by three radii: the entry path radius, circulating path radius and the exit path radius. It is assumed that the vehicle is 2 m wide, and that it will maintain a minimum clearance of 0.5 m from a roadway centerline or concrete curb and the drawn edge of the splitter island. Therefore, the centerline of the vehicle path is 1.5 m away from a roadway centerline, 1.5m away from the concrete curb and 1.0 m away from the drawn line of the splitter island (Figure 3.) [4, 6].

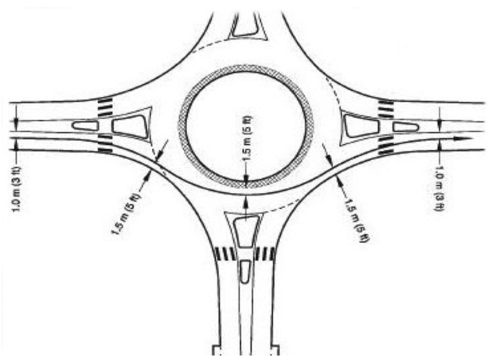


Figure 3 Layout of the fastest vehicle path through a roundabout [6].

The fastest vehicle path for the drive through manoeuvre is a series of reverse curves (to the trajectory on the right a trajectory on the left continues, and then a right trajectory again takes place). In cases with no central island the vehicle path will be straight. Therefore, the radius of reverse curve depends on the smallest radius that usually appears while the vehicle turns around the central island. For all the approaches it is necessary to sketch the fastest vehicle paths, which can be done by using the AutoCAD tool [1, 4, 5, 6].

2.3 Vehicle path radii on roundabouts

With the goal of achieving an adequate design speed for the fastest vehicle path it is necessary to check the consistency/permanence for all movements. Speed consistency results in a higher level of traffic safety by decreasing the speed difference among conflicting traffic flows. Also, it simplifies the task of merging into the conflicting traffic stream, minimizing critical gaps, thus optimizing entry capacity. Therefore, for each approach it is necessary to check five critical radii: R1 – entry path radius; R2 – circulating path radius; R3 – exit path radius; R4 – left-turn path radius; R5 – right-turn path radius (Figure 4.). It is necessary to note that the values of these radii are not equal to the presumed curb radii [4, 6].

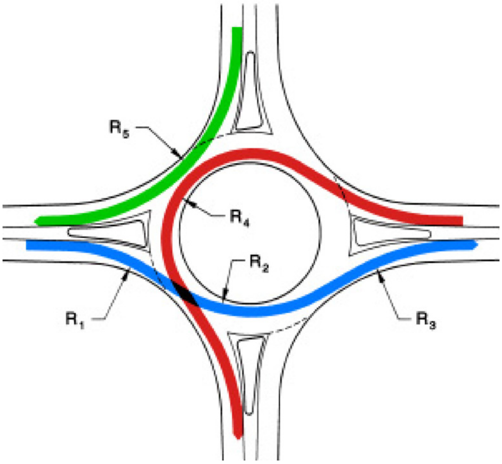


Figure 4 Vehicle path radii [6]

It is desirable that on the fastest vehicle path, R1 is smaller than R2, which on the other hand needs to be smaller than R3. This ensures that speeds will be reduced to their lowest level at the roundabout entry and will thereby reduce the likelihood of loss-of-control crashes. In cases where the R1 ‹ R2 condition is not possible to satisfy, then it is necessary that R1 is greater than R2 provided the relative difference in speeds is less than 20 km/h. At mini and small roundabouts with higher intensity of pedestrian traffic, and with the goal of maximizing exit speeds, it is desirable that the exiting radii are equal or inconsiderably greater than R2. By checking the values of the radius R4 the condition that maximum speed difference between the entrance flow and the circulatory roadway flow is smaller than 20km/h is assured. The design speed for the R5 radius should be the same as the maximum design speed of the whole roundabout and not higher than 20km/h from the design speed of the R4 radius, which has a conflict point with the R2 [4, 6].

3 Analysis of the research results

The analysis of the speed on the vehicle movement trajectory in the conditions of a normal flow has been conducted on four single-lane roundabouts with four single-lane approaches, situated in central and periphery part of Zagreb. Design parameters of the observed roundabouts are shown in Table 2. Because of the design characteristics of the chosen roundabouts and analyzed traffic flow movements, speed on the vehicle path through a roundabout from every leg approach has been analyzed. The vehicle speed at the entrance (V_1), in the roundabout (V_2) and at the roundabout exit (V_3) was measured, as well as the corresponding radii (R_1,

R_2 and R_3). Speed on right turns (V_4) and left turns (V_5) through the roundabout, respectively the radii (R_4 and R_5) because of previously mentioned reasons are not the research topic.
Measurements of the approaching vehicle speed were done in cooperation with The Ministry of the Interior on the 07.07.2008., Tuesday, in morning peak-hours, in intervals of 5, 10 and 15 minutes. Meteorological conditions were appropriate, it was mostly sunny with slight clouds which allowed good visibility on all intersections, and the roadway was dry. In accordance with the specifics of analyzed intersections, and needed information on the traffic flow speed and technical characteristics of the instrument a MULTANOVA 6F instrument was chosen and used. During measurements a police automobile without police markings was used along with an officer in a civil uniform, in order to reduce the possibility of spotting the police, which could affect the driver reactions [1, 5]. Measurements of the approaching speed, the speed in the circulatory roadway, and the speed at the roundabout exit were done on the 15.09.2011., Thursday, in the morning peak-hours, in intervals of 15 minutes with a GPS installed in a personal vehicle. Also, meteorological conditions were appropriate, sunny weather enabled good visibility on all intersections, and the roadway was dry.

Table 2 Design elements of chosen roundabouts [1, 5]

Red. br.	Oznaka	Naziv raskrižja/prometnice	Kružni kolnik				Privozi			Napomena
			D_v [m]	D_u [m]	tk [m]	q [±%]	n [-]	b_p [m]	uvoz/izvoz [m]	n-tračnost [k/p]
	a) m -	Mini RKT (Dv ≤ 26 m)								
01.	RKTm	Sveti Duh - Kunišćak	20,0	6,0	7,0	-1,5	3	7,1	3,5/3,6	1/1
	b) M -	Mala RKT (22 m ≤ Dv ≤ 35 m)								
02.	RKTM	Petrova - Jordanovac	25,0	12,0	6,5	-1,5	4	8,0	3,5/4,5	1/1
03.	RKTM	Voćarska - Bijenička	22,0	13,0	4,5	-3,0	4	8,0	4,0/4,0	1/1
04.	RKTM	Radnička cesta - Petruševec 1.	40,0	28,0	6,0	-0,5	4	6,5	3,0/3,5	1/1

Depiction: D_v – outer roundabout diameter [m], D_u – inner roundabout diameter [m], tk – circular roadway width [m], q - superelevation rate on circular roadway gradient [±%], b_p – approach leg width [m].
Table 3 shows data acquired with speed measurements for vehicle movement trajectories through the roundabout. The design speed of the roundabout was calculated in accordance with the formula (1) with the help of measured radii in the layouts [4, 5, 6], while on the specimen of 50 measurements the average measured vehicle speed was depicted, as well as the deviating values.

Table 3 Design speed and average measured vehicle speed on chosen intersections

Naziv raskrižja / Oznaka privoza	Polumjer trajektorija			Projektna brzina			Broj mjerenja	Izmjerena prosječna brzina			Odstupanje od projektne brzine		
	R_1 [m]	R_2 [m]	R_3 [m]	V_1 [km/h]	V_2 [km/h]	V_3 [km/h]	N	V_1 [km/h]	V_2 [km/h]	V_3 [km/h]	V_1 [%]	V_2 [%]	V_3 [%]
Sveti Duh - Kunišćak													
Privoz 1-3	10	20	28	19,02	26,91	31,83	50	17,52	24,04	29,34	-7,91	-10,65	-7,84
Privoz 3-1	10	20	28	19,02	26,91	31,83	50	16,20	24,60	26,90	-14,85	-8,57	-15,50
Petrova - Jordanovac													
Privoz 1-3	10	20	29	19,02	26,91	32,40	50	16,96	23,40	28,02	-10,85	-13,03	-13,51
Privoz 3-1	10	20	29	19,02	26,91	32,40	50	16,52	23,31	25,56	-13,37	-13,36	-21,11
Privoz 4-2	12	20	25	20,84	26,91	30,08	50	20,42	25,34	28,78	-2,02	-5,82	-4,33
Privoz 2-4	15	20	25	23,30	26,91	30,08	50	24,34	26,56	29,78	+4,46	-1,28	-1,00
Voćarska - Bijenička													
Privoz 1-3	15	20	25	22,68	26,19	29,28	50	20,36	24,90	30,24	-10,23	-4,92	+3,28
Privoz 3-1	15	20	25	22,68	26,19	29,28	50	21,15	24,34	28,76	-6,74	-7,06	-1,77
Privoz 4-2	10	20	28	18,52	26,19	30,99	50	21,66	24,48	30,40	+16,97	-6,52	-1,89
Privoz 2-4	10	20	28	18,52	26,19	30,99	50	21,38	25,96	29,78	+15,46	-0,87	-3,89
Radnička cesta - Petruševec 1.													
Privoz 1-3	15	25	30	23,71	30,60	33,53	50	20,86	27,22	34,64	-12,01	-11,06	+3,32
Privoz 3-1	15	25	30	23,71	30,60	33,53	50	19,76	26,30	32,40	-16,65	-14,06	-3,36
Privoz 4-2	15	25	25	23,71	30,60	30,60	50	22,74	29,74	34,34	-4,07	-2,82	+12,21
Privoz 2-4	15	25	25	23,71	30,60	30,60	50	23,12	28,38	32,88	-2,47	-7,27	+7,44

For comparison of acquired results, speed on the vehicle path through the roundabout is shown in the following graphs.

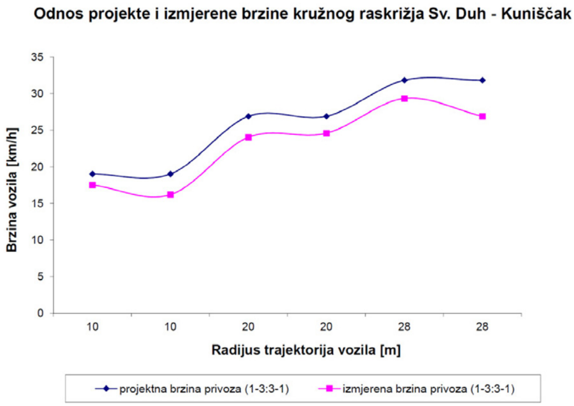


Figure 5 The relationship of the design speed and the measured speed in the roundabout Sv. Duh–Kunišćak

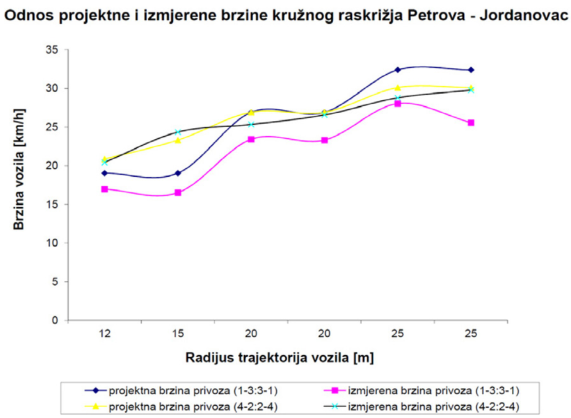


Figure 6 The relationship of the design speed and the measured speed in the roundabout Petrova–Jordanovac

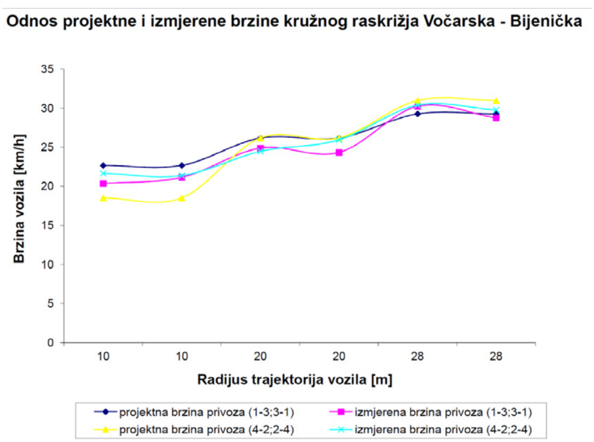


Figure 7 The relationship of the design speed and the measured speed in the roundabout Voćarska–Bijenička

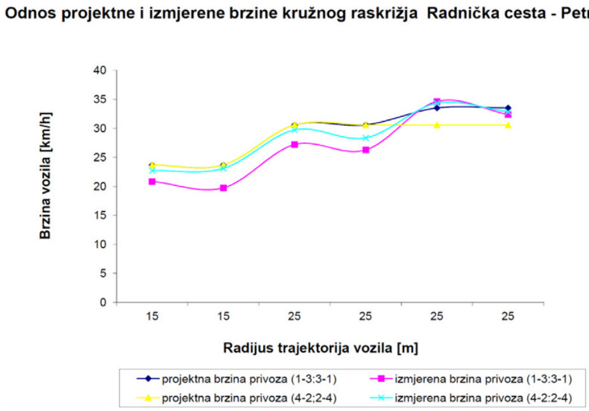


Figure 8 The relationship of the design speed and the measured speed in the roundabout Radnička– Petruševec

On the Figures 5, 6, 7 and 8 the relationship between the measured vehicle speeds is shown, respectively from every approach. The diagrams show that the conditions R_1, $R_2 < R_3$ have been satisfied while designing the roundabout. Respectively, the lowest measured speed is the one on the vehicle path around the central island, while the highest speeds are measured at the roundabout exit.

Research results also show that average values of measured speed at the entrance are smaller than 35 km/h, and are in accordance with the recommendations from Table 2. However, on certain intersections deviations of measured individual speeds from the design speed were noted (Table 3.). On the Sv. Duh–Kuniščak intersection the average measured speed from the approach leg 3 to the approach leg 1 was 15.50% smaller than the design speed. On the Petrova–Jordanovac intersection the average measured speed from the approach 3 to the approach 1 had a 21.11% smaller value than the design speed, while the actual speed from the approach 2 to the approach 4 was 4.46% higher than the design speed. On the Voćarska–Bijenička intersection the measured speed from the approach 1 to the approach 3 was lower than the design speed for 10.23%, while the same speed was 16.97% higher than the design speed for the movement from the approach 4 to the approach leg 2. On the Radnička–Petruševec intersection the average measured speed from the approach 3 to the approach 1 was 16.65% smaller than the design speed, while for the movement from the approach 4 to the approach 2 the speed difference was 12,21% (actual speed was higher than the design speed). These deviations are a result of specific spatial locations of mentioned roundabouts, their design elements and characteristics of traffic flow during the measurements.

4 Conclusion

Designing and dimensioning of roundabouts with small diameters in urban areas ($D_v \le 35$ m) presents a complex problem where it is necessary to determine a series of elements out of which the size of the inner and outer diameter of the roundabout, the number and width of approaching legs are of most importance. The mentioned elements considerably affect the vehicle path through the roundabout, i.e. the speed of the vehicles that has direct impact on the roundabout safety and capacity [1, 4, 5, 6].

Te research on the vehicle path speed in normal conditions was conducted on four single-lane roundabouts with four single-lane approaches in the City of Zagreb. The research results showed that the basic design condition R_1, $R_2 < R_3$ was satisfied. Looking at traffic intersections, deviations between the design and actual speed are spanning from -21.11% to +16.69%, and are the result of the location and function of the intersection in the road network, design elements and characteristics of traffic flow as well as driver conduct during the measurements.

It should be pointed out, that in the Republic of Croatia there is no existing legislative regulative for roundabout design. In the existing guidelines 'Smjernice za projektiranje raskrižja u naseljima sa stajališta sigurnosti prometa' [7] conditions/rules for determining the design speed are not defined. Therefore, guidelines 'Roundabouts; An Informational Guide, 2000, Federal Highway Administration'[6] can serve the designers while designing the roundabout speed, which the conducted research confirms.

The conducted research on the vehicle path speed should serve as a basis for future thorough and systematic research of the causality of speed and vehicle path on roundabouts. The research should comprise a larger number of roundabouts with a bigger number of test samples, and the speed for left and right turns through the roundabout. Furthermore, it would be necessary to bring into connection the effect of the design speed with the level of safety on the existing roundabouts, analyzing traffic accident by types and samples.

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