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PRINCIPLES OF ROUNDABOUT SAFE DESIGN

ZÁSADY BEZPEČNÉHO NÁVRHU OKRUŽNÍ KŘIŽOVATKY

Abstract

The contribution presents the main principles of roundabout safety layout. It is result of the research project for the Ministry of Transport of Czech Republic No. CG911-008-910. The name of the project is Influence of structural elements geometry on safety and fluency of operation on roundabouts and possibility of rise crashes prediction. The research includes a large set of roundabouts based on the analysis accident rates in proportion to the traffic flow. The comparison of the geometry and relative accident rates resulted in recommendations for the design of roundabouts. In this article the attention is paid to the most important factors affecting safety at the roundabouts.

Keywords

Traffic safety, roundabout, crash rate, available speed.

Abstrakt

V článku jsou prezentovány hlavní zásady bezpečného uspořádání okružní křižovatky, které jsou výsledkem výzkumného projektu Ministerstva dopravy České republiky číslo CG911-008-910 Vliv geometrie stavebních prvků na bezpečnost a plynulost provozu na okružních křižovatkách a možnost predikce vzniku dopravních nehod. Výzkum byl prováděn na početném souboru okružních křižovatek na základě hodnocení nehodovosti v poměru k intenzitám dopravy. Po srovnání geometrie a relativní nehodovosti vyplynuly závěry pro navrhování okružních křižovatek. Pozornost je v článku věnována nejdůležitějším faktorům ovlivňujícím bezpečnost na okružní křižovatce.

Klíčová slova

Bezpečnost dopravy, okružní křižovatka, relativní nehodovost, dosažitelná rychlost.

1 INTRODUCTION

Nowadays, the roundabouts are frequently used types of intersections. This is because they are safer in comparison with classical types of intersections. Single-lane roundabout with one traffic lane at the entry, on the circulatory roadway and at the exit, has a minimum number of conflict points and there are no vehicle-vehicle crossing points. Yet on some roundabouts occur more traffic accidents than on others. According to current knowledge, the traffic safety is related to the roundabout geometry. This hypothesis was, among others, the aim of research for Ministry of Transport in the Czech Republic.

The Department of Transport Constructions, Faculty of Civil Engineering of the VŠB-Technical University of Ostrava was in 2009 and 2010 involved in a two-year research project for the Ministry of Transport. The project number CG911-008-910 name is The influence of structural

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elements geometry on the safety and fluency of operation at roundabouts and possibility of rise crashes prediction. This work presents some important principles for the roundabout safe arrangement which emerged from the results of the researched project [3].

For a detailed analysis of the geometrical layout and accident rate relationship was within the frame of solution of the research project chosen a representative collection of roundabouts with representation of various types of geometrical layout and miscellaneous traffic load values. The basic data collection covers 104 roundabouts from the whole Czech Republic comprising three to six leg roundabouts - 87 hereof are single-lane roundabouts and 17 double-lane roundabouts. The selection of roundabout types is based on a relative occurrence of individual types of the roundabouts in the Czech Republic (the majority is four-leg roundabouts, less than 10 % are multi-lane roundabouts). From the surveyed basic collection was during the research eliminated roundabouts with bypasses, on-connections, traffic lights and mini roundabouts to create a consistent collection which could be unambiguously statistically evaluated according to the influence of certain controlled geometrical parameters and other factors of the accident rate at roundabouts. Reduced final data collection includes 69 roundabouts - 59 hereof are single-lane roundabouts and 10 hereof are double-lane roundabouts.

Covering all roundabouts there were collected data about crashes which were recorded by the Police of the Czech Republic in years 2007 and 2008. Data about crashes recorded in years 2009 and 2010 could not be used for the research due to the fact that there was a significant increase of the financial worth of damages in which the accident report is required. Because most accidents at roundabouts result in damages below the financial threshold, the present traffic accidents evidence does not present sufficient basis for statistical analysis of accident rate for the purposes of the research project.

For selected roundabouts were obtained data about the traffic flow. Traffic volumes were obtained by counting from the national traffic census, from earlier traffic researches or from own traffic researches realized directly within the frame of the research project solution. To determine traffic volumes and additional information about the behavior of vehicles in the real traffic, videos were taken at selected roundabouts, which were also used to make a video analysis of conflict situations [2]. Consequently the accident rate and its relation with the geometrical layout were evaluated at selected roundabouts. The accident rate, i.e. number of crashes per million vehicles entering to a roundabout, was used as an objective indicator to compare the safety of roundabouts with different geometric layouts.

2 THE ROUNDABOUTS SAFETY

The roundabouts safety is mainly due to:

- minimizing of the total number of conflict points;
- elimination of the vehicle-vehicle crossing points;
- ensuring low vehicle speed.

2.1 Minimizing of the total number of conflict points

Minimizing of the total number of conflict points is naturally reached at a roundabout with one traffic lane on a circulatory roadway, at the entries and at the exits. Four-leg roundabout organized in this way has only 8 conflict points, while the classical four-legged intersection has 32 conflict points in total.

However, the situation changes dramatically at a multi-lane roundabout of a classical arrangement with parallel lanes on a circulatory roadway. A connection of every leg with double-lane entry and exit to a double-lane circulatory roadway means a rise of 10 conflict points – see fig. 1. Four-leg roundabout with two traffic lanes on a circulatory roadway and on all entries and exits has on its connection 40 conflict points in total, that means 40 places with a potential possibility of accidents between vehicles rises. Furthermore, it should be considered that other conflict points arise when changing lanes on a double-lane circulatory roadway. Experience shows that significantly more accidents occur on multi-lane roundabouts in comparison with single-lane roundabouts.

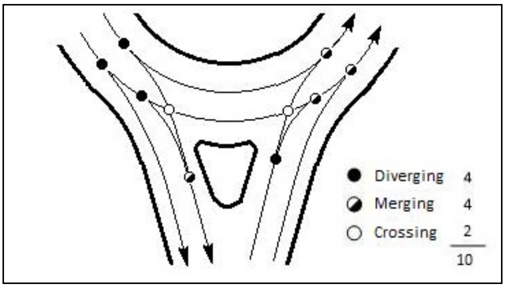

Fig. 1: Conflict points at the entry and at the exit of a classical double-lane roundabout

Within the frame of our research, more than four times higher average accident rate was discovered at double-lane roundabouts of a classical arrangement in comparison with single-lane ones - see table 1. As it is clear from the research findings, in terms of traffic safety a single-lane roundabout on a circulatory roadway at entries and at exits is clearly more suitable.

Tab. 1: Values of relative accident rate on single-lane and double-lane roundabouts

Roundabout		Relative accident rate in years 2007 – 2008 (number of accidents per million vehicles entering the roundabout)		
number of lanes on a circulatory roadway	number of surveyed roundabouts	minimal	maximal	average
1	59	0	3,07	0,52
2	10	0,40	6,26	2,79

That corresponds with previously published findings of the Institute of Traffic Engineering of the capital city Prague (ÚDI Praha) [5] which on their web site at that time featured the usual relative accident rate of each type of level crossings in Prague – see fig. 2.

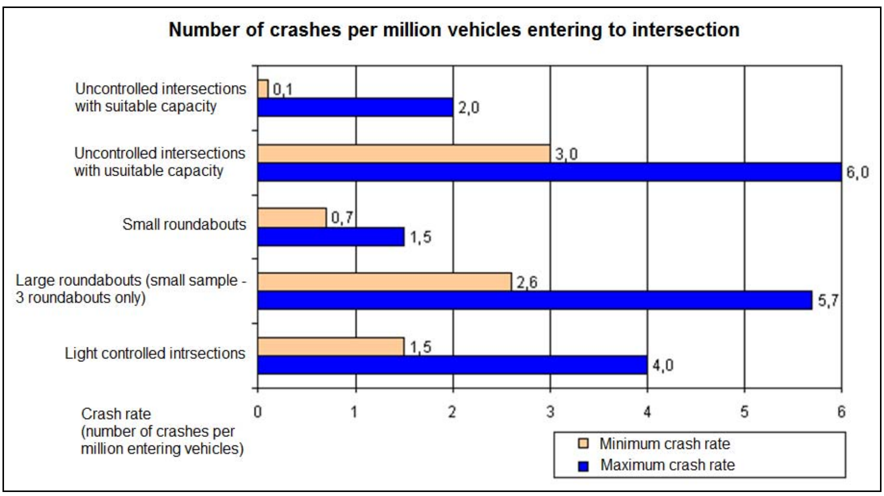

Fig. 2: Usual relative accident rate of level crossings in Prague, year 2005 [5]

The graph in figure 2 also shows approximately four times higher accident rate on double-lane roundabouts compared with single-lane ones. According to the earlier terminology valid in the Czech Republic, the single-lane roundabout was named a small roundabout and the double-lane roundabout a large roundabout. ÚDI Praha is from 1. 1. 2008 under the name Department of Transportation Engineering (ÚDI) integrated to the Technical Administration of Roads of the capital city of Prague (TSK Praha) and its original web site is no longer available.

2.2 Elimination of the vehicle-vehicle crossing points

Elimination of the vehicle-vehicle crossing points is the main reason of generally higher safety of a roundabout in comparison with a classical level crossing. At a single-lane roundabout, the crossing conflict points are eliminated. However, at multi-lane roundabouts crossing conflict points arise at entries and at exits (fig. 1) and when changing lanes on a circulatory roadway as well. Yet it is in the crossing conflict points where accidents with the most serious consequences might happen.

2.3 Ensuring low vehicle speed

Ensuring low vehicle speed is a natural result of directional curvature of vehicles path when passing a roundabout. For the traffic safety is ideal when the all vehicles velocity at a roundabout is approximately the same. That makes deciding easier in giving priority to circulating vehicles at an entry, in entering a gap in circulating traffic flow and in an easier exiting. However, there has to be an appropriate geometrical layout to avoid a direct transit through the roundabout and to ensure that there will be no jump velocity change when passing subsequent geometrical elements of a roundabout.

It is recommended to assess the ratio between achievable speed on vehicle paths in the consequential traffic movements, namely:

- the difference of available speed at approaches to a roundabout (on an acces road) and at an entry path curve (passage around the right curb of pavement of the entry roadway);
- the difference of available speed at an entry path curve (passage around the right curb of pavement of the entry roadway) and at a circulating path curve during a passage around the central island;
- the difference of available speed at a path curve during a passage around the central island and at an exit path curve (passage around the right edge of the exit roadway).

The available speed when driving at a path curve is determined depending on the radius of the vehicle roadway and the superelevation in accordance with generally well-known formula:

$$v_o = 3{,}6 \cdot \sqrt{R \cdot g_n \cdot (f + 0{,}01 \cdot p)} = \sqrt{127 \cdot R \cdot (f + 0{,}01 \cdot p)} \qquad (1)$$

where:

v_o – is the available speed at a path curve [km/h],

R – radius of a vehicle path curve [m],

g_n – normal gravitational acceleration [m/s^2],

p – superelevation at a path curve [%] and

f – side friction factor according to ČSN 73 6102 [1] – see table 2.

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Tab.2: Side friction factor values according to [1]

Side friction factor								
v (km/h)	60	50	40	35	30	25	20	15
f	0,17	0,19	0,23	0,25	0,28	0,31	0,34	0,40

The available speed at an approach is determined mostly by its approach curves ahead of entering a roundabout:

1. If the communication at an approach is led in a path curve, the available speed is determined by the above-mentioned formula (1).
2. If the communication at an approach is led in a straight directional or in a path curve of a large radius, the available speed is influenced especially by an arrangement of road space or in some case traffic signs and pavement markings:
    - Tightly adjacent house-building, not very comfortable width of road and communication bordered by curbs contribute to maintaining low vehicle velocity. Speed limit of 50 km/h compliance can be expected at approach sections of local communications arranged in this way.
    - Offset or non-existent house-building, comfortable width arrangement of road and curbs absence at an approach contribute to higher vehicle velocity, disregarding the maximum speed limit laid down by valid regulation or locally modified by traffic signs. The achieved vehicle velocity of 70 km/h and higher has to be considered at sections of roads arranged in this way.

The required reduction of the available vehicle velocity at an approach can be provided by hardened verge narrowing, inserting a sufficiently long splitter island to a roundabout leg – see fig. 3, constructing raised curbs defining minimal functionally capable roadway width at an approach section of a communication, eventually by constructing a retarding directional curvature at an approach – see fig. 4.

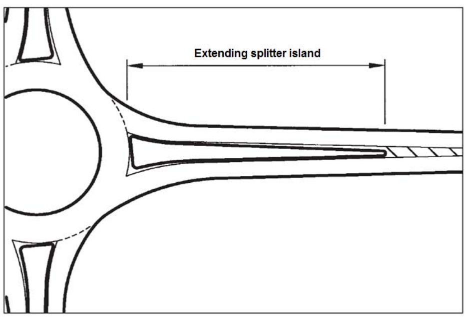

Fig. 3: Extending splitter island for the approach speed reduction according to [4]

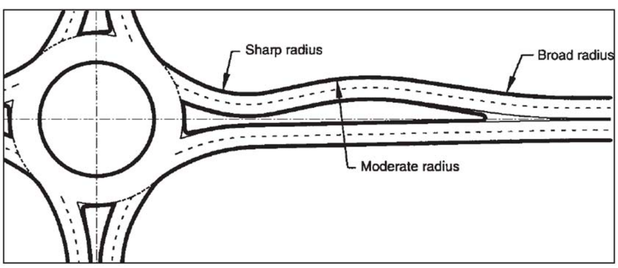

Fig. 4: Approach curves for the approach speed reduction according to [4]

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Ideally, the compared available speeds should be the same, because of safety ensuring and fluency operation they should not differ by more than 20 km/h. That eliminates the need for sudden hard braking which in result can turn to a skid of a braking vehicle or to a rear-end collision caused by a next not properly braking vehicle.

For assessing the speed ration at a four-leg roundabout are crucial:

1. the fastest vehicle path from the entry to the first exit (right-turn movement),
2. the fastest vehicle path from the entry to the second exit (passage through a roundabout),
3. the fastest vehicle path from the entry to the third exit (left-turn movement).

As the fastest vehicle path is considered to be the least curved vehicle path indented by 1,5 m, at most by 2,0 m though, from the edges limiting design elements, i.e. from the curvature of the right edge of the line at the entry, from the edge of the central island and from the curvature of the right edge of the line at the exit.

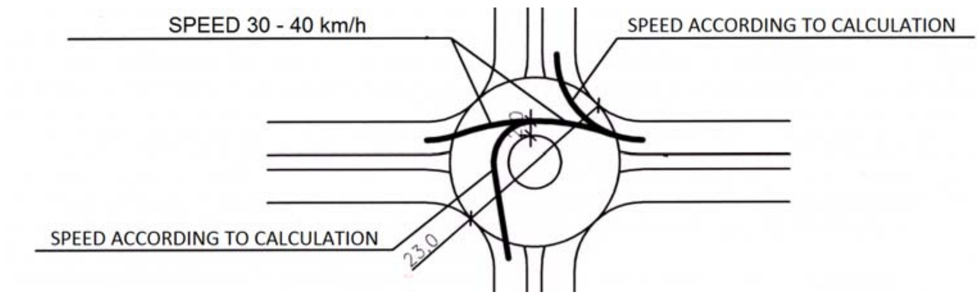

Fig. 5: Passage through the smallest roundabout of the inscribed diameter D = 23 m
(with a smaller diameter it is a mini roundabout then)

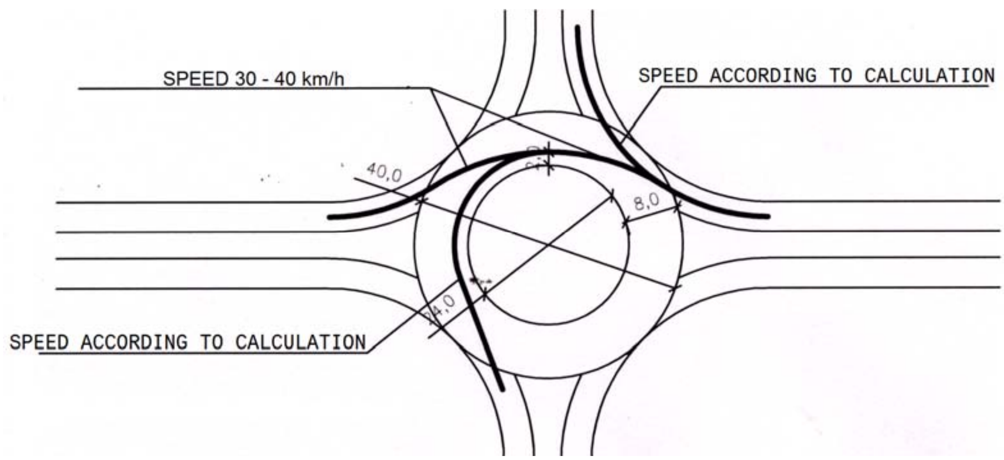

Fig. 6: Passage through an optimal roundabout of the inscribed diameter D = 40 m

3 ROUNDABOUT SAFETY EVALUATION

As mentioned in the introduction, 69 roundabouts placed around the whole Czech Republic, 59 hereof single-lane and 10 double-lane roundabouts were included in the surveyed collection. The accident rate at spirally arranged multi-lane roundabout was not taken with regard to minimal occurrence of this roundabout type in the Czech Republic at the time of the research project.

Geometrical parameters and relative accident rate of the evaluated roundabouts were examined, i.e. number of accidents registered by the Police of the Czech Republic to one million vehicles entering the roundabout. After comparing geometry and relative accident rate the research resulted in following conclusions.

- Single-lane roundabouts on the circulatory roadway, at entries and at exits placed on roads with speed limit to 50 km/h (structurally secured) are definitely the safest.
- Location of a single-lane roundabout on roads with the available approach speed of 70 km/h and higher is accompanied by an increase of relative accident rate to double compared to similar single-lane roundabout placed on roads with speed limit of 50 km/h.
- Roundabout with a classical double-lane arrangement of its circulatory roadway and with double-lane entries and exits records 4,4 times higher accident rate compared to a single-lane roundabout placed on roads with same speed conditions at its approach sections.

As results from this evaluation, for the maximal safety ensuring roundabouts should preferentially be designed in the single-lane layout. It is also necessary to ensure adequate reduction of the available vehicle velocity by an appropriate construction design at the approach sections of roads before entering the roundabout. Speed limit reduction at straight approach legs only by traffic signs is not efficient enough for a real increase of safety.

4 CONCLUSION

Safety at a roundabout is conditioned by a complex of coefficient factors like design, permitted and available speed at entries and at circulatory roadway of a roundabout, sight conditions and movement of pedestrians and cyclists, depending on the design elements of a roundabout, location of vertical and horizontal traffic signs, eventually on roadside safety elements and public lighting, and also the quality of the road surface. In this context it is necessary to include especially effects of the largest design vehicles on a central island apron whose construction is extremely stressed and it is a place where defects often occure with the impact on traffic safety. The influence of vehicle wheels dynamic effects when driving on the apron surface can be evaluated e.g. according to [6].

Based on the research it can be recommended to pay more attention to correct design of the whole roundabout geometry. Special attention should be paid to the roundabout design of highways and urban roads with design speed over 50 km/h where it is necessary to ensure reduction of the vehicle velocity by an appropriate design at the approach to the roundabout before entering the roundabout. Roundabout geometry design in conditions of lower traffic volumes, when minimal interaction with other vehicles in the traffic flow is for drivers tempting to subconscious increasing of speed especially at an approach, also deserves more attention.

The use of the classical double and multi-lane layout of roundabouts seems to be inappropriate. Double-lane roundabouts record a slightly higher daily capacity though, usually about 30 to 40 thousand vehicles per a day. However, with increasing traffic volume the accident rate rapidly rises and it is several times higher than the accident rate of the single-lane roundabouts in conditions of similarly high traffic volume level.

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