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ANALYSIS OF SIGHT DISTANCE AT AN AT-GRADE INTERSECTION

Ivana Pranjić[1], Aleksandra Deluka-Tibljaš[1], Dražen Cvitanić[2], Sanja Šurdonja[1]
[1] *University of Rijeka, Faculty of Civil Engineering*
[2] *University of Split, Faculty of Civil Engineering, Architecture and Geodesy*

Abstract

Maneuvering distance and stopping sight distance are important traffic safety elements at an at-grade intersection. Croatian official standard for sight distance calculation (HRN.U.C4.050) dates from 1990. This regulation treats sight distance values in a very simplified way. The mentioned regulation seems to be outdated since various researches of real traffic conditions at an at-grade intersection have been conducted to detect significant factors influencing sight distance. In this paper an overview of sight distance calculation methods according to Croatian official standard (HRN.U.C4.050), and additionally according to Croatian guidelines for urban intersection design from the traffic safety aspect (Hrvatske ceste, 2004.), American guidelines for geometric design of highways and streets – The Greenbook (AASHTO, 2001.) and PIARC Road Safety Manual (2003.) is done. These calculation methods were applied at an at-grade intersection in City of Rijeka, where necessary calculation parameters (vehicle speed, friction coefficient) were collected at the site. This intersection is distinctive for greater amount of traffic accidents due to lack of maneuvering and stopping sight distance. The conducted analysis of different sight distance calculation methods shows that inspected calculation methods differ for calculation parameters and consequently given sight distance values. The sight distances obtained with suggested calculations from Croatian standard are in all cases less conservative than the sight distances calculated with other, more detailed methods. This is why a revision of current Croatian regulations concerning sight distance is suggested.

Keywords: sight distance, at-grade intersection, calculation models

1 Introduction

Sight distance is an important element of traffic safety especially at non-signalised intersections. Insufficient sight distance often represents one of major causes of traffic accidents resulting in property damages but also more or less severe road users injuries. At intersections, the available sight distance must be sufficient to allow users to safely complete each permitted but non-priority manoeuvre [1]. Various intersection types and right-of-way rules determine sight distance criteria needed to ensure safety requirements for all motorised road users. One of the major factors that influence sight distance is traffic speed on major and minor roads. Systematic measurement and analysis conducted in Ireland in the period between 2005. and 2011. demonstrate that 82% of car drivers surveyed exceeded the 50 km/h limit on national roads in urban areas and 53% of these drivers exceeded the speed limit by 10 km/h or more [2]. The traffic safety data collected and published by Croatian Ministry of Internal Affairs show that in 2012 [3] 74% of all road traffic accidents happened in urban areas and more than 31% happened in the intersection area. It is even more interesting that 34% of all accidents were connected with turning manoeuvres or happened as vehicle impact from the back, where

the reasons for these types of accidents could easily be addressed to problems of exceeded speed and insufficient sight distance for safely vehicle stopping.
In this paper an overview of sight distance calculation method according to Croatian official standard HRN.U.C4.050 (further in the text Croatian standard) [4] is done. Croatian standard dates from 1990. and has some limitations in comparison with widely used methods because it is based on limited number of parameters which are assumed on theoretical basis without their adjustment to local conditions or without being explicitly measured on site [5]. Croatian guidelines for urban intersection design from the traffic safety aspect (further in the text Croatian Guidelines) [6] were also analyzed from the sight distance aspect and compared with the official Croatian standard. The sight distance calculation methods according to American guidelines for geometric design of highways and streets – The Greenbook (AASHTO, 2001.) (further in the text The Greenbook) [7] and PIARC Road Safety Manual (PIARC, 2003.) (further in the text RSM) [1] were analyzed and compared to given Croatian legislative and recommendations.
These calculation methods were applied, as a case study [8], at an at-grade intersection in City of Rijeka in order to compare the results of different methods and make conclusion about suitability of Croatian Standard after 25 years of use without any serious revision. In this case study necessary calculation parameters, such as vehicle speed and friction coefficient, were collected at the intersection site to compare values calculated with those data with usually used theoretical values and to establish their influence on final results. The conclusions of the case study are explained in the paper too.

2 Sight distance calculation methods

Sight distance calculation methods differ regarding parameters on which they are based. Main parameters that can be found in all of methods are vehicle speed (design speed or actual 85th percentile speed) and time interval needed to perform a certain turning manoeuvre or to stop the vehicle before hitting an obstacle. In this chapter an overview of calculation methods according to Croatian standards and Croatian guidelines [4],[6] and some foreign sight distance calculation standards methods [1], [7] is done.

2.1 Manoeuvring distance calculation methods

Manoeuvring distance refers to sufficient sight distance needed for safe completion of all permitted but non-priority manoeuvres at an at – grade intersection, which includes right turn, crossing or left turn from minor road and left turn from major road [1].
Croatian standard from 1990 is based on presupposing driver's reaction time and acceleration. The Standard considers difference between intersections with obligatory stops on minor road and yield intersections. The left picture in Figure 1. and Equation (1) refer to sight distance at intersections with stops, while right picture in Figure 1. and Equation (2) refer to sight distance on yield intersections.

$$P_g = v_g t_s = v_g \left(t_r + \sqrt{\frac{2D}{a_s}} \right) \tag{1}$$

Where:
P_g – sight distance on major road;
v_g – design speed on major road (km/h);
t_r – reaction time (s), t_r = 1,5 s;
D – crossing intersection length, D = L_k + L_v;
L_k – distance between two opposite intersection legs;
L_v – vehicle length (approx. 6 m);
a_s – acceleration rate for PV, a_s = 1,5 m/s^2.

$$P_s = v_s t_r + \frac{v_s^2}{2g\left(f_t \pm \frac{i}{100}\right)} \quad (2)$$

Where:
P_s – sight distance on minor road;
v_s – design speed on minor road (km/h);
t_r – reaction time (s), t_r = 1,5 s;
f_t – tangential friction coefficient on minor road;
i – vertical slope (%) of minor road.

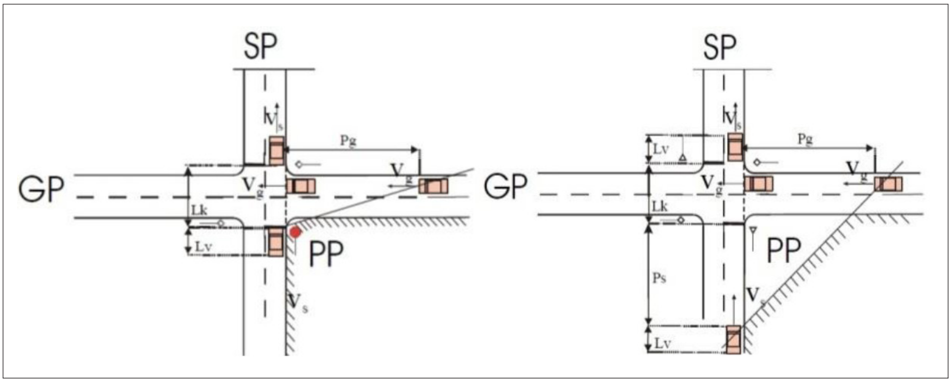

Figure 1 Sight distance for obligatory stop on minor road (left) and yield intersection (right); Croatian standard [4]

The previous research from Cvitanić et al. [5] pointed out few deficiencies of the Standard: exclusion of the necessary manoeuvring time for left or right turn but giving only time necessary for crossing the intersection, inclusion of the unnecessary part of L_k width from the edge of the carriageway to the STOP line on the outbound intersection leg, and also usage of the projected speed v_r of minor road for calculating sight distance on yield intersections which is unrealistic because vehicle decelerates when approaching the intersection.
Another Croatian document that deals with sight distance issues is Guidelines for urban intersection design from the traffic safety aspect dating from 2004 [6]. The Guidelines give some recommendations for necessary sight distance according to v_{85} speed without explaining its usage, but simply recommending certain values. For example, recommended sight distance value at intersection with v_{85} = 60 km/h as 85th percentile of speed on major road is 85 m [6].
Since the Croatian sight distance calculation methods exclude time intervals necessary for turning manoeuvres or presuppose sight distance according to approaching vehicle speed, the chosen foreign standards for comparison were AASHTO's Greenbook [7] and PIARC's RSM [1] which both include necessary time intervals for different turning manoeuvres, while PIARC's RSM also takes into consideration the real vehicle speed on intersection.
The Greenbook [7]) gives a calculating expression (Equation 3) very similar to one from the Croatian standard (Eq.1) with the main difference of including different time intervals necessary for different turning manoeuvres. These time intervals (expressed in seconds) are given in Table 1. for different vehicle types. Their adjustment is necessary for minor road's vertical slope greater than 3% and for each extra passing lane [5]. This standard adopts road design speed for sight distance calculation, which can be disadvantage in cases where actual speed is much greater than the design speed.

$$P_g = 0{,}278 v_g t_g \qquad (3)$$

Where:
P_g – sight distance;
v_g – design speed (km/h);
t_g – time interval (depending on manoeuvre type).

Table 1 Time intervals for different turning manoeuvres, The Greenbook [7]

MANOEUVRE	PV	HV	HV + trailer
Left turn	7,5 s	9,5 s	11,5 s
Right turn/ Crossing	6,5 s	8,5 s	10,5 s
Left turn from major road	5,5 s	6,5 s	7,5 s

The main difference between PIARC's [1] and AASHTO's [7] calculation is the speed considered for sights distance calculation. PIARC's RSM considers v_{85} speed, or 85th percentile of speed on major road, which is much more realistic than design which is taken into consideration in both Croatian and US Standard methods. The RSM also gives some manoeuvring gaps or time intervals for different countries, which are shown in Table 2.

$$D = \frac{v_{85} t}{3{,}6} \qquad (4)$$

Where:
D – sight distance (m);
v_{85} – 85th percentile of speed on major road (km/h);
t – manoeuvring gap (s).

Table 2 Manoeuvring gaps for different countries, PIARC's RSM [1]

COUNTRY	MANOEUVRING GAP for PV
France/Spain	6-8 s
England	5-8 s
USA	6,5-7,5 s

After calculating or adopting sight distance values according to requirements of chosen calculation method it is necessary to check the sight triangles, which represent areas inside intersection zone where no obstacle should be present.

2.2 Stopping sight distance calculation methods

Stopping sight distance represents available sight distance which must be sufficient for the driver to safely stop the vehicle when approaching an intersection at a reasonable driving speed (v_{85}) [1]. Croatian legislative gives no distinctive regulation for stopping sight distance calculation on major road. The above mentioned Croatian standard for sight distance calculation on intersections with stops on minor road considers only sight distance for major roads when crossing the intersection, when the vehicle from minor road has already stopped. The Guidelines have some recommendations for necessary stopping sight distance on roads according to road category, 85th percentile of approach speed and vertical slope, but without any explanation when to apply minimum or maximum value from the given range [6]. For example, for roads in urban areas with 85th percentile speed of 50 km/h recommended stop-

ping sight distance ranges from 40 to 50 m, which is a significant length in terms of stopping sight distance (10 m equals almost two vehicle lengths).
The Greenbook recommends calculating stopping sight distance as the sum of the distance traversed during the brake reaction time and the distance to brake the vehicle to stop (Equation 5) [7]. This formula includes design speed v_g, but also adopted values of presupposed brake reaction time t_r =2.5 s and deceleration rate a = 3.4 m/s² (Eq. 5) derived from previously conducted studies.

$$SSD = 0{,}278 v_g t_r + 0{,}039 \frac{v_g^2}{a} \tag{5}$$

PIARC's RSM gives stopping sight distance calculating expressions in two forms, once including longitudinal friction coefficient f_l based on approaching speed (Equation 6) and once including the same deceleration rate as The Greenbook (Equation 7) [1]. It also includes initial speed v_i, or 85th percentile of approaching vehicle speed. The reaction time and longitudinal friction coefficient are not strictly defined values, but lie within typical values intervals [1].

$$SSD = \frac{v_{85} t_r}{3{,}6} + \frac{v_{85}^2}{254\left(f_l \pm \frac{G}{100}\right)} \tag{6}$$

$$SSD = \frac{v_{85} t_r}{3{,}6} + \frac{v_{85}^2}{254\left(\frac{a}{g} \pm \frac{G}{100}\right)} \tag{7}$$

Where:
SSD – stopping sight distance;
$v_i = v_{85}$ – initial or 85th percentile of speed;
t_r – reaction time;
f_l – longitudinal friction coefficient;
a – deceleration rate, a=3.4 m/s²;
G – grade percent (vertical slope in (%).

3 Sight distance calculation – Case study in the City of Rijeka

Faculty of Civil Engineering Rijeka, Chair for Transportation engineering in cooperation with Department for municipal system, City of Rijeka conducted a case study of available sight distance at an urban intersection in the City of Rijeka. The aim of the study was to test different methodologies of sight distance calculation as well as to suggest improvements in given situation [8]. The chosen intersection was three – leg uncontrolled intersection with obligatory STOP sign, distinctive for greater amount of detected traffic accidents. The most common accident type detected at the site are improper left turn from minor road (8 of 11 recorded accidents were of this type), which can be connected with insufficient sight distance for drivers approaching intersection from the minor road as well as vehicle impact from the back (3 of 11 recorded accidents) connected with insufficient stopping sight distance.

3.1 Site measurements

The measurements conducted on the studied intersection were speed measurements and friction coefficient measurements [8]. Actual vehicle speed was measured with traffic counters Datacollect SDR Traffic+ positioned in few characteristic points inside the intersection area with continuous traffic flow measurement during 3 workdays.

Friction on main road was measured with a fixed slip measurement device installed in a vehicle with travel speed of approximately 50 km/h, where the average measured friction coefficient for both traveling directions was f_L = 0,55. This data was used in stopping sight distance calculations according to PIARC's formulation (Eq 6.). Frictional characteristics on minor road were determined by SRT Pendulum device suitable for friction coefficient prediction at lower traveling speed. However, stopping sight distance for the minor road was calculated with PIARC's Equation 7, including deceleration rate a= 3,4 m/s^2 due to lack of information for transferring SRT value into coefficient of friction.

3.2 Comparison of sight distances calculated on the basis of different standards

The analysis of available sight distance was conducted by calculating sight distance values using Standard and comparing it with recommended values from the same Standard and Guidelines. Sight distance according to Standard was calculated with real speed measured on the intersection – v_{85} which was established to be approximately 10 km/h higher than presupposed design speed v_g (50 km/h).
Sight distance calculations were also made according to The Greenbook and PIARC's RSM in order to compare recommended and calculated values. Since The Greenbook also presupposes design speed, the calculation was made with the actual measured speed and compared with values calculated with design speed. Table 3. summarizes all conducted calculations of sight distance based on different calculation methods, according to conducted case study [8].

Table 3 Sight distance (SD) calculation results and mutual comparison between different standards and recommendations

STANDARD/ GUIDELINE	SPEED (design v_g/actual v_{85})	SIGHT DISTANCE (recommended/calculated)		
Croatian standard HRN U.C4.050	v_g = 50 km/h	$SD_{rec.}$ = 91 m		
	v_{85} = 60 km/h	$SD_{calc.}$ = 96 m		
Croatian Guidelines	v_{85} = 60 km/h	$SD_{rec.}$ = 85 m		
AASHTO's Greenbook	v_g = 50 km/h	$SD_{rec.L}$ =105 m	$SD_{rec.R}$ = 91 m	$SD_{rec.LM}$ = 77 m
	v_{85} = 60 km/h	SD_{calcL} =126 m	SD_{calcR} =109 m	SD_{calcLM} = 92 m
PIARC's RSM	v_{85} = 60 km/h	$SD_{calc.L}$ = 135 m	$SD_{calc.R}$ = 115 m	$SD_{calc.LM}$ =99 m

Calculation results given in Table 3. show that required values for calculated sight distance vary by as much as 50 meters. Also, there is a quite difference detected between calculated sight distance needed for different manoeuvring types, and neither Standard nor Guidelines, usually used in Croatia, give distinctive difference between manoeuvring types. Another significant difference can be detected by comparing sight distance values calculated according to design speed vg and measured speed v_{85} when comparing foreign standards that include different time intervals for different manoeuvring types. The difference between calculated values is by as much as 15-20%, where the calculated sight distance value regarding the measured vehicle speed is approximately 20 m longer than the sight distance calculated with the design speed. Finally, after detecting real sight distance values needed according to measured speed, sight triangles were created to visualize given values and determine whether available sight distance ensures safe traffic conditions on analysed intersection. Figure 2. presents sight triangle created using calculated sight distance for the same vehicle speed according to the Standard (upper scheme) for left turn from minor road and the sight triangle for the same manoeuvre according to PIARC's RSM recommendations (lower scheme). From both sight triangle visualisations it is obvious that there is a lack of visibility for the vehicles turning left according to eastern intersection approach, and also from the western approach considering PIARC's sight distance values.

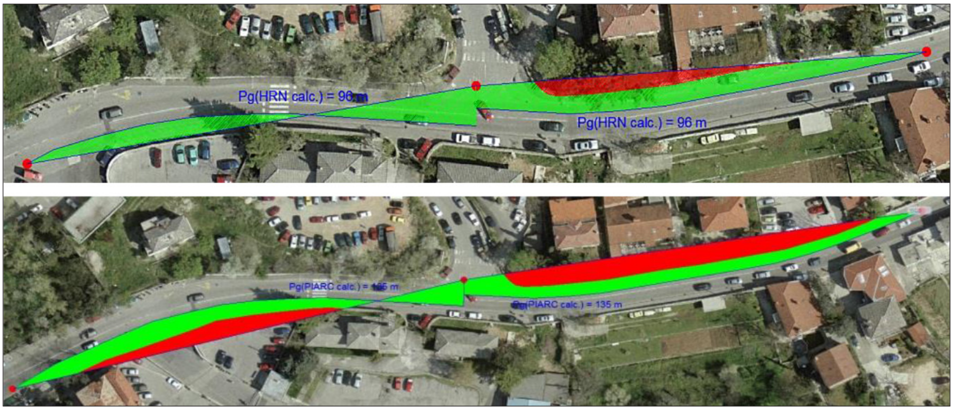

Figure 2 Sight triangle visualisations for left turn from minor road considering calculated sight distance using Croatian standard (upper scheme) and PIARC's RSM (lower scheme)

Since the calculated values of sight distance mostly depend on vehicle speed approaching the intersection, the conclusion in this case was that mandatory speed reduction would definitely contribute to necessary sight distance decrease and improvement of traffic safety conditions on this intersection.

The same type of comparison was used for stopping sight distance values calculation according to different standards and recommendations, observing stopping sight distance from STOP line on minor road and possible conflict points inside intersection area between vehicles on major and minor road [8]. Stopping sight distance for pedestrian crossings on both major and minor road was also reviewed and calculated using the same equations and parameters as for the previous calculations. Table 4. summarizes stopping sight distance values calculated with recommended and measured speeds according to standards and recommendations mentioned in previous chapter.

Table 4 Stopping sight distance (SSD) calculation results and mutual comparison between different standards and recommendations

STANDARD/ RECOMMENDATION	MAJOR ROAD		MINOR ROAD	
Croatian Guidelines	$v_{85(rec.)}$* = 50 km/h	SSD = 40 m	V_{85}= 40 km/h	SSD = 25 m
	$v_{85(real)}$ = 60 km/h	SSD = 60 m		
AASHTO's Greenbook	$v_{g(rec.)}$ = 50 km/h	SSD = 64 m	$v_g = v_{85}$ = 40 km/h	SSD = 46 m
	$v_{85(real)}$ = 60 km/h	SSD = 83 m		
PIARC's RSM	$v_{85(real)}$ = 60 km/h	SSD = 51 m	$v_{85(real)}$ = 40 km/h	SSD = 42 m

Figure 3 Sight triangle visualisations for pedestrian crossings on major and minor road considering calculated stopping sight distance using Croatian guidelines (left scheme) and AASHTO's Greenbook (right scheme)

Figure 3. shows sight triangles for actual stopping sight distance needed for major and minor road to ensure safe traffic conditions for pedestrians on intersection, according to Guidelines (left scheme) and The Greenbook (right scheme). The sight triangle visualisations show general deficiency of visibility for pedestrians crossing minor road, but also insufficient visibility for pedestrians crossing major road according to US recommendations.
In this case can also be noticed difference among calculated values of sight distances for vehicles and pedestrians. In all cases Croatian methods allow solutions in which lower safe distances (both manoeuvring and stopping sight distances) are acceptable.

4 Conclusion

Analyses of parameters included in calculation of manoeuvring sight distance and stopping sight distance in different methods (Croatian, USA, PIARC) and their application in real intersection conditions confirmed limitations of Croatian standards in the case of calculation of sight distance. Comparison of the calculated distances in the case of three leg non-signalized intersection showed that distances calculated on the basis of Standard were significantly lower than those calculated on the basis of Greenbook or RSM. Among three methodologies PIARC's RSM happened to be the most conservative in calculated distances, by suggesting longer necessary distances than other methods and it has to do with the fact that they take into consideration measured (v_{85}) and not design speed (v_g). The other problem with Croatian Standard is that they don't respect the fact of different time intervals needed for different manoeuvring directions at the intersection.
These are the reasons why Croatian regulations prescribe lower levels of sight distances which can potentially result in lower level of traffic safety so their revision can be recommended.

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