EVALUATION OF AVAILABLE SIGHT DISTANCE ESTIMATION METHOD ON RURAL ROADS ACCORDING TO CROATIAN REGULATION

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Abstract

Every driver must have sufficient visibility (sight distance) in front of the vehicle to be able to stop the vehicle in time in front of an obstacle on the road at the posted speed. This means that the available sight distance (ASD) in front of the driver must be greater than or equal to the stopping sight distance (SSD) required to stop the vehicle in front of the obstacle. The estimation method to determine the ASD varies from country to country because the SSD values, the position and height of the driver's eye and the obstacles are different. What they have in common is that the ASD on the road is first checked separately in the horizontal and then in the vertical direction, i.e., a 2D sight distance check. With the help of road design software, the sight distance on the newly designed roads can be checked simultaneously in the horizontal and vertical direction, i.e., a 3D sight distance check. In order to determine the advantages and disadvantages of 2D sight distance testing compared to 3D testing, different road models were designed according to Croatian regulation in Autodesk Civil 3D and Bentley OpenRoads Designer software. The test results showed that the sufficient ASD achieved by the 2D sight distance check on all road models does not guarantee sufficient ASD in the 3D sight distance check. To achieve sufficient ASD in the cut area of the road cross-section in crest vertical curves it is not enough just to widen the shoulders or verges, but it is also necessary to choose the radii of the vertical curves accordingly, usually larger than the radii that pass the 2D sight distance test. The above facts show that it is necessary to perform a 3D sight distance test for roads, as this also takes into account certain cross-sectional features that have a negative effect on the driver's field of vision.

Keywords: rural roads, geometric design, Croatian regulation, available sight distance, 2D vs 3D analysis, crest vertical curves

1 Introduction

Guidelines and regulations for the geometric design of roads provide minimum standards that must be met to ensure safe and efficient traffic flow. The sight distance available to road users is one of the most important elements of safe road design. Road design must ensure that the available sight distance (ASD) in front of the vehicle is greater than or equal to the stopping sight distance (SSD), which is the minimum distance drivers need to cross the various road segments and stop the vehicle in time to avoid an obstacle on the road while travelling at the posted speed. The length of the SSD and the position and height of the driver's eye and obstacles vary from country to country [1-4]. What they have in common [1-4] is that they provide a similar estimation method for the ASD on the road, first in the horizontal and then in the vertical direction, i.e., a two-dimensional estimation of the ASD.

According to [5], the existing ASD estimation methods are two-dimensional (2D) and do not consider different visibility conditions. The different conditions of the existing roadside features or geometric elements under which 3D ASD estimation is important were identified. The results of the comparison show the importance of considering 3D modelled sight distance when evaluating the associated risk either during road design or during service life. In addition, the results showed that the ASD modelling approach can have a significant impact on estimating safety during road design as it is considered more realistic when evaluating the associated risk either during road design or during service life. Reliability estimates (based on minimum horizontal sight line offsets from current minimum design criteria) and SSD distributions (based on individual driver characteristics) showed that drivers were much more likely to have insufficient SSD when approaching horizontal curves than within curves [6]. To improve design consistency, the use of calculated horizontal sight line offsets beyond the curve limits (approach and departure tangents) is proposed to provide additional sight distance to drivers near the curve [6]. Stopping sight distance is one of the factors influencing traffic accidents [7]. Therefore, researchers [7] attempted to investigate the probability of accidents at some locations on existing roads by calculating the 3D stopping sight distance and using the speed of drivers in free-flowing traffic and GIS software. It was concluded that the 3D estimation of sight distance is far better and more accurate than the two-dimensional sight distance resulting from the existing regulations, and that the software can be used to better serve the existing routes, and that by analysing and identifying points with a higher probability of accidents, a solution can be found to improve safety and reduce the number of traffic accidents. In this way, the results of this study can pave the way for improving the geometric design of existing roads and prioritising the correction of accident-prone points on existing roads.
Based on previous studies and a review of road design regulations and guidelines [1-7], a study was conducted to evaluate the method of estimating ASD according to Croatian regulation. The evaluation was carried out by comparing the results of 2D and 3D sight distance tests on roads. The 3D sight distance tests were carried out using Autodesk Civil 3D (C3D) and Bentley OpenRoads Designer (ORD) software. The tests were carried out on road models designed with straight lines and horizontal curves (minimum radii) with transitions (minimum length) between them for different design speeds. In terms of vertical alignment, the road models were designed in crest curves with minimum radii and in cut cross-section. The aim of this study is to make it clear to planners and decision makers that it is not enough to carry out a mandatory 2D sight distance check, but that a 3D sight distance check and the correct selection of horizontal and vertical elements on the roadway are also required.

2 Methodology

The research methods include analysis of Croatian design regulation for rural roads [2], creation of road models in ORD and C3D software, analysis of ASD for different horizontal radii and deflection angles, for different vertical crest curve radii and grade changes on different road cross-sections based on different design speeds, and comparison and analysis of the obtained results.

3 Croatian regulation for the design of rural roads

According to [2], SSD and passing sight distance (PSD) are checked when determining sight visibility on the road. It is assumed that the presence of SSD is a fundamental factor for road safety, while the presence of PSD is an indicator of the level of road standard achieved. To determine the ASD tests on roads are carried out first in the horizontal and then in the vertical direction, separately for each direction of travel (Figure 1). This is a 2D sight distance test that does not consider certain cross-sectional features that may have a negative effect on the driver's field of vision. The required SSD in the horizontal direction is ensured by removing all obstacles on the inside of the horizontal curve, i.e., by ensuring the required horizontal sight offset (HSO) (Figure 1). The HSO is calculated from the driver's line of sight along a path according to following equation (Figure 1):

$$HSO=\frac{SSD^2}{8R_{Dp}} \tag{1}$$

where:
SSD – stopping sight distance,
R_{Dp} – radi of driver path,
HSO – horizontal sightline offset.

The ASD on the road in the vertical direction depends on the selected radius of the crest vertical curve. The minimum radius of crest curves depends on the required SSD (for the selected speed and longitudinal grade), the eye and the obstacle height (Figure 1) and is calculated according to the following equation:

$$R_{Vmin}=\frac{SSD^2}{2\left(\sqrt{h_e}+\sqrt{h_o}\right)^2} \tag{2}$$

where:
R_{Vmin} (m) – minimum radius of crest curve,
SSD (m) – stopping sight distance,
h_e (m) – eye height (1.0 m),
h_o (m – obstacle height (0.25 m for speeds between 40 and 90 km/h).

According to [2], ASD is equal to SSD if the minimum radius of the crest curves determined from (2) is applied. If, for any reason, the ASD on a part of the road is lower than the SSD, the speed must be limited to the level for which the SSD is justified.

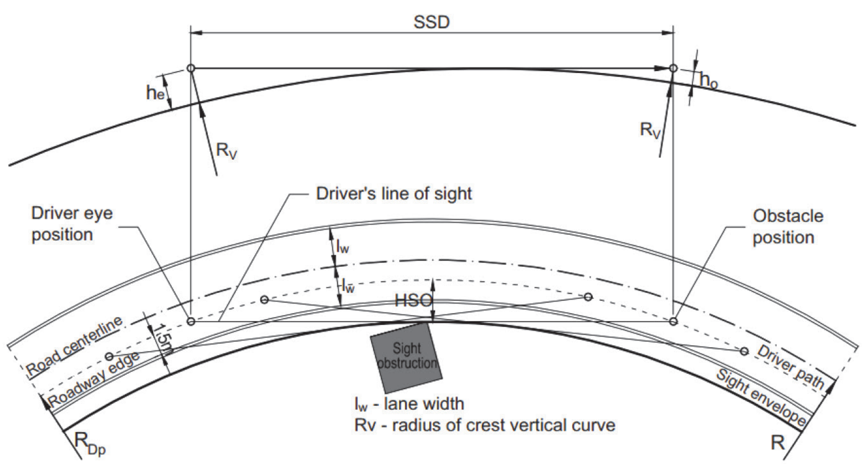

Figure 1 Sight visibility test on road in horizontal and vertical direction according to [2]

4 Research

The tests were carried out on various examples of road models designed in accordance with Croatian regulation using ORD and C3D software. Before the main test, preliminary sight distance tests were carried out to test the quality of the software. The first preliminary sight distance tests were performed on road models designed with a horizontal straight line and a vertical crest curve rounded by minimum radii for different grade changes Δs = 2, 4, 6 and 8%. The second preliminary sight distance test was conducted on road models designed with horizontal curves (minimum radii) with transitions (minimum length) and straight-line entrances and exits with constant longitudinal grade, and the verges were widened according to the HSO calculated according to (1) and shown in Table 2.

A total of 60 road models were designed for the main test, whereby the horizontal alignment consisted of a entry and exit straight-line and a curve with transitions. The horizontal curves had minimum radii for speeds of 50 to 90 km/h and different deflection angles α = 30, 60 and 90°, as indicated in Table 1 and shown in Figure 2. In terms of vertical alignment, the road models had a vertical crest curve with a minimum radius for a given speed with a grade change Δs = 2, 4, 6 and 8% and were in a cut (below the terrain level) (Figure 2). In cross section, the road models were two-lane (Figure 3), and the dimensions of the lanes, gutters, and verges are shown in Table 1. The cross slope of the road was 2.5 % on the straight section and 7 % on the circular curve (Figure 2).

For each road, the SSD lengths were selected from the regulation [2] based on the longitudinal grades and speeds, and the minimum radii of the vertical crest curves according to (2) and the HSO according to (1) were calculated (Table 2).

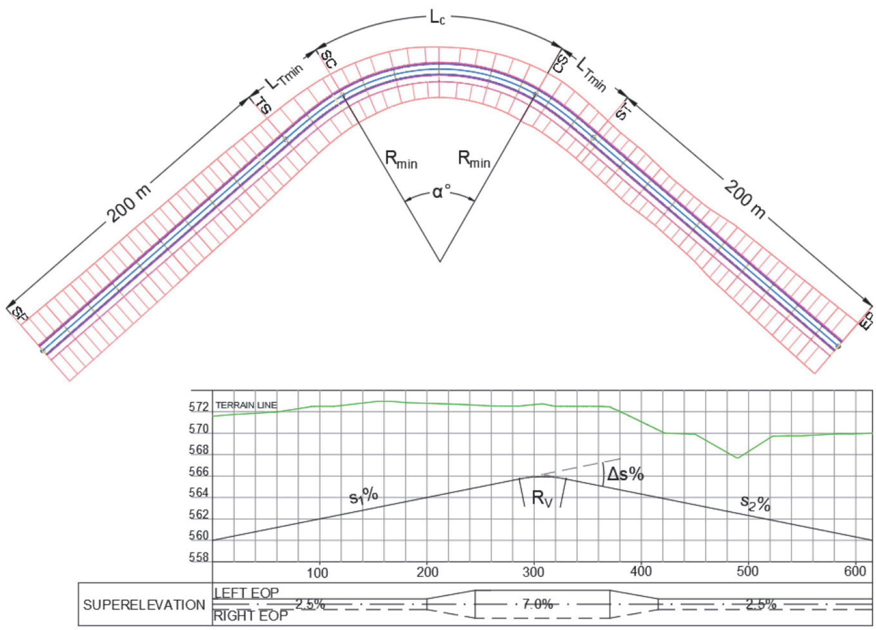

Figure 2 Example of horizonal and vertical alignment

Table 1 Input parameters of the horizontal road axis and cross section.

V [km/h]	R_{min} [m]	R_{Dp} [m]	L_{Tmin} [m]	Lane width [m]	Shoulder lane width [m]	Gutter width [m]	Curb & verge width [m]
50	75	73.50	35	3.0	0.2	0.5	0.5
60	120	118.50	45	3.0	0.2	0.5	0.5
70	175	173.50	50	3.0	0.3	0.5	0.7
80	250	248.38	60	3.25	0.3	0.5	0.7
90	350	347.50	65	3.5	0.5	0.5	1.0

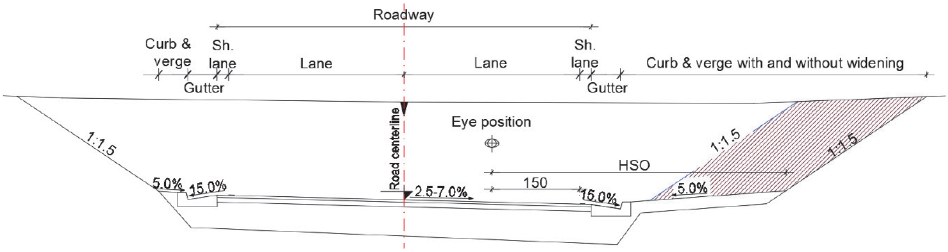

Figure 3 Example of road cross section

Table 2 Stopping sight distance, crest vertical curve minimum radii and horizontal sightline offset

V [km/h]	Δs = 2% (1%+1%)			Δs = 4% (2%+2%)			Δs = 6% (3%+3%)			Δs = 8% (4%+4%)		
	SSD [m]	R_{Vmin} [m]	HSO [m]	SSD [m]	R_{Vmin} [m]	HSO [m]	SSD [m]	R_{Vmin} [m]	HSO [m]	SSD [m]	R_{Vmin} [m]	HSO [m]
50	50	556	4.3	50	556	4.3	53	624	4.8	54	648	5.0
60	70	1089	5.2	70	1089	5.2	72	1152	5.5	74	1217	5.8
70	94	1964	6.4	96	2048	6.7	98	2134	7.0	100	2222	7.3
80	122	3308	7.5	125	3472	7.9	127	3584	8.2	130	3756	8.6
90	155	5339	8.7	159	5618	9.1	163	5904	9.6	168	6272	10.2

5 Results

The results of the first preliminary sight distance tests on road models showed that the minimum radii of the crest vertical curves provide sufficient ASD, and the results of the second tests showed that the verge widening (calculated with respect to the HSO) is sufficiently wide to provide the sufficient ASD. The preliminary test proved the quality of the software, and the main test was then carried out on different road models. The test results showed the following (Table 3):

- for certain road models, due to the length of the vertical curves (in cases where the vertical curve overlaps horizontal curve and enters the straight road section), no sight visibility test was performed, as such examples of road models are not used in practice,
- for certain road models, the widening of the verges is not sufficient to achieve the sufficient ASD (ASD was smaller than SSD) on the roads, as the elements of the cross section (height and slope of the curb and verge) influence the ASD,

- in order to achieve sufficient ASD on certain road models, the radii of the crest vertical curves had to be increased, i.e., the minimum radii of the crest vertical curves defined on the basis of the Croatian regulation (2D) for certain speeds and grade changes are not sufficient to achieve sufficient ASD when checked in the software (3D) (ASD was smaller than SSD),
- the applied radii of vertical curves (R_{Vapp}), that ensure the sufficient ASD on the road models on average, are significantly larger than the minimum, especially at higher speeds and grade changes,
- the applied radii of the crest vertical curves, that ensure the sufficient ASD on the road models in the section, were determined iteratively and are the same for both software, i.e., they provide the same sight distance results.
- the deflection angle of the circular arc does not affect the sufficient ASD, except at a speed of 80 km/h and Δs = 6% and 70 km/h and Δs = 8%, but the differences in radii are minimal (100 m).

Table 3 Crest vertical curve minimum and applied radius

V [km/h]	Δs = 2% (1%+1%)		Δs = 4% (2%+2%)		Δs = 6% (3%+3%)		Δs = 8% (4%+4%)	
	R_{Vmin} (2D) [m]	R_{Vapp} (3D) [m]	R_{Vmin} (2D) [m]	R_{Vapp} (3D) [m]	R_{Vmin} (2D) [m]	R_{Vapp} (3D) [m]	R_{Vmin} (2D) [m]	R_{Vapp} (3D) [m]
				30°				
50	556	556	556	556	624	624	648	700
60	1089	1089	1089	1089	1152	1300	1217	1500
70	1964	1964	2048	2600	2134	2800	2222	n/a
80	3308	4100	3472	5100	3584	n/a	3756	n/a
90	5339	8000	5618	n/a	5904	n/a	6272	n/a
				60°				
50	556	556	556	556	624	624	648	700
60	1089	1089	1089	1089	1152	1300	1217	1500
70	1964	1964	2048	2600	2134	2800	2222	3000
80	3308	4100	3472	5100	3584	5400	3756	n/a
90	5339	8000	5618	9100	5904	n/a	6272	n/a
				90°				
50	556	556	556	556	624	624	648	700
60	1089	1089	1089	1089	1152	1300	1217	1500
70	1964	1964	2048	2600	2134	2800	2222	3100
80	3308	4100	3472	5100	3584	5500	3756	6100
90	5339	8000	5618	9100	5904	10300	6272	n/a

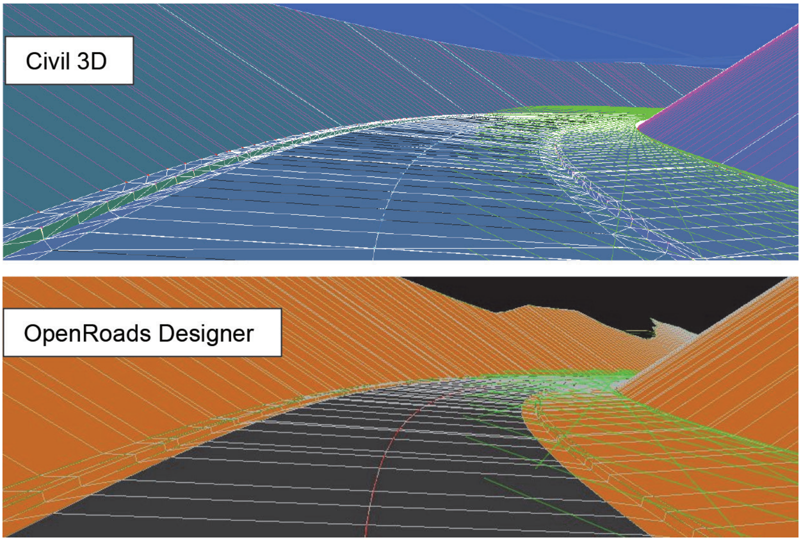

Figure 4 Examples of a sight visibility test on road in C3D and ORD

6 Conclusions

The test results showed that the sufficient ASD achieved by the 2D sight distance test on all road models does not guarantee sufficient ASD in the 3D sight distance test, i.e., in the cut area of the road cross-section in crest vertical curves it is not sufficient just to widen the verges, but it is also necessary to choose the radii of the vertical curves accordingly, usually larger than the radii that will pass the 2D sight distance test. The above facts show that it is necessary to carry out a 3D sight distance test for roads that have combination of horizontal and vertical curves in alignment because it also considers certain cross-sectional features that have a negative impact on the driver's field of vision. Specialized software's are great help for doing that.
The results of this research can help planners and decision makers to understand that it is not enough to perform a mandatory 2D sight distance test, but that a 3D sight distance test and the correct selection of horizontal and vertical elements on the roadway are also required to ensure safe and efficient traffic flow.

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