



ROAD WIDENING IN CURVES ACCORDING TO CROATIAN, REGULATIONS, GERMAN GUIDELINES AND COMPUTER SIMULATION OF VEHICLE MOVEMENT

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Abstract

Road widening is necessary in curves because the rear wheels of the vehicle are usually not steerable and their trajectory is described with a smaller radius than that of the front wheels. The maximum value of the road widening depends on the turning angle, the radius of the curve and the length of the vehicle, the wheelbase and the front overhang. The required road widening increases gradually with a higher turning angle and decreases gradually as the vehicle leaves the curve and continues in the direction. This paper presents the determination of road widening in curves according to the Croatian regulations, German guidelines and computer simulation of the vehicle movement. The road widening determined according to the above mentioned guidelines and regulations for certain design vehicles (truck with trailer, semi-trailer truck and bus), different radii of circular curves (from 12.5 to 500 m) and different turning angles (from 45 to 270°) is compared with the road widening determined by computer simulation of vehicle movement with the Autodesk software Vehicle Tracking.

Keywords: road widening, circular curves, design vehicles, vehicle trajectories

1 Introduction

When the vehicle travels through a horizontal curve, it occupies a greater width of road than when it travels in one direction. The front wheels turn and the rear wheels do not follow their trajectory and describe an arc of smaller radius than the front wheels (Figure 1). Therefore, it is necessary to widen the road in curves, depending on the size of the radius of the horizontal curve and the dimensions of the design vehicle [1]. As a rule, the widening of the road in curves for all lanes is performed on the inside of the curve, in exceptional situations it can be performed on the inside and outside of the curve or only on the outside of the curve (for example, roads with hairpin curves) [1]. Usually the transition from the non-widened road to the widened road is performed along the length of the transition. Along the entire length of the arc, the road should be widened to the full amount [1-3]. This paper gives an overview of the currently valid regulations and guidelines from Croatia [1, 4] and Germany [2, 5], which refer to the determination of the dimensions of road cross-section elements (width of lanes and width of curbs), dimensions of design vehicles operating on public roads and other methods for determining road widening in circular arcs.

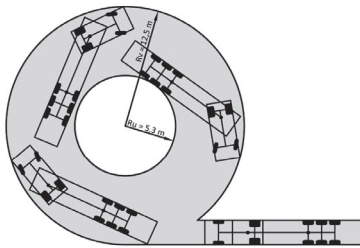


Figure 1 Simulation of vehicle movement in circle

Based on the formulas defined in the above-mentioned regulation and guidelines, the values of required widening in curves were calculated for different radii of circular arcs from 12.5m to 500 m. The calculated values of roadway widening in circular curves were compared with the values obtained from the simulation of vehicle movement truck with trailer, semi-trailer truck and bus. Vehicle movement simulation was performed using Autodesk software Vehicle Tracking [6]. The vehicle trajectories were drawn for radii from 12.5 to 500 m and for different turning angles from 45° to 270°. A total of 162 combinations were processed. The research was carried out to determine the relationship between the required values of widening obtained according to different criteria described in regulations and guidelines [1, 2] and the values obtained based on the simulation of movement of design vehicles [3].

2 Guidelines, regulations and computer simulation of vehicle movement

Extent of road widening on curves are usually specified in guidelines and regulations. The only accurate method to determine the road widening is by driving the vehicle in a real traffic situation or on a test site [7, 8]. However, conducting such a test is time-consuming, organizationally demanding and expensive, so computer simulations have been developed. The following text describes how the widths of the traffic and shoulder lanes are chosen, how the road widening along the entire arc is determined, and how the dimensions of the design vehicles are chosen according to regulations and guidelines from Croatia [1, 4, 9] and Germany [2, 5]. The characteristics of the software used to simulate the vehicle movement are also briefly described.

2.1 Croatian Regulations

Traffic lanes are part of the roadway and must be wide enough for vehicles to move freely. The width of the traffic lanes S_{pt} (Table 1) depends on the design speed V_p [1]. The shoulder lanes S_{rt} (Table 1) are made continuous on the whole road section and their width depends on the road category and the width of the lane [1].

Table 1 Traffic and shoulder lane widths depending on the design speed [1]

V_p [km/h]	≥ 120	100	90	80	70	60	50	40
S_{pt} [m]	3.75	3.50	3.50	3.25	3.00	3.00	3.00	2.75
S_{rt} [m]	0.50	0.50	0.50	0.30	0.30	0.20	0.20	-

According to the regulation [1], the widening of a lane along an arc of a circle for radii $R \geq 45$ m is determined according to the following formulas:

$$\Delta s = 10/R \quad (1)$$

$$\Delta s = 32/R \quad (2)$$

$$\Delta s = 42/R \quad (3)$$

Δs [m] - lane widening,
 R [m] - curve radius.

Equation (1) is used to determine the lane widening for a passenger cars, eqn (2) for trucks and buses, and eqn (3) for trucks with a trailers, semi-trailer trucks and articulated buses. The detailed dimensions of the design vehicles (axle distances, front and rear overhang lengths, attachment points, etc.) for determining the lane widening in circular curves are not defined in regulation [1]. According to the regulation [9], the maximum permissible lengths of vehicles in traffic on Croatian roads are: 12.0 m for trucks, 16.50 m for trucks with semi-trailer, 18.75 m for trucks with trailer, 13.5 m for buses with two axles, 15.0 m for buses with three axles and 18.75 m for articulated buses. The only recent document in Croatia that defines design vehicles with all dimensions is the “Guidelines for the Design of Roundabouts on State Roads” [4], only trucks with trailers and semi-trailers.

Road widening values are usually determined for both lanes for the same design vehicle. In the circular arc, road widening values have a constant value, and the road is usually widened for both (or more) lanes on the inside of the curve. Based on equations (1) (2) and (3), the road widening values can also be determined for curves with a radius of 25 to 45 m when the turning angle of the curve is smaller than the right angle of 90° [1]. If the radius of the curves is less than 45 m and the turning angle is greater than or even 90° , the road widening should be determined based on the trajectories of the design vehicle [1]. Road widening is not provided if the sum of individual lane widening Δs for the total number of lanes in the curves is not more than 0.2 m and the width of the roadway (traffic and shoulder lanes) is less than or equal to 6.0 m, and if the sum of individual lane widening Δs is not more than 0.3 m and the width of the roadway is greater than 6.0 m. The transition from the non-widened road to the widened road in the circular arc is carried out along the length of the transition and the change is non-linear.

2.2 German guidelines

In the German guidelines [2], the lane widths are related to given road cross-sections and are in the range of 2.50 to 3.50 m. A lane width of 2.50 m applies to a two-directional road without a dividing line, for road class EKL 4 and a design speed of 70 km/h. A lane width of 3.25 m represents the width of the second or third lane at the cross sections for roads of class EKL 1, EKL 2 and EKL 3 for the design speed of 90, 100 and 110 km/h. A lane width of 3.50 m is the usual lane width at the cross sections for roads of classes EKL 1, EKL 2 and EKL 3 for the design speed of 90, 100 and 110 km/h. The usual width of the shoulder lane is 0.50m and can be increased to 0.75 m on sections of three-lane roads to provide a stopping width for maintenance vehicles [2]. According to the German guidelines [2], in curves with radius less than 200 m, the road must be widened by a corresponding amount, whereby the widening must take place over the entire length of the arc at the inner edge of the curve. The roadway widening is calculated according to the following formula [2]:

$$i = 100/R \quad (4)$$

i [m] - roadway widening,
 R [m] - curve radius.

The transition from the non-widened road to the widened road in the circular arc is carried out along the length of the transition and the change is usually linear [2]. The dimensions of 13 relevant vehicles (passenger cars, buses, trucks, etc.) are defined in the guidelines [5].

2.3 Computer simulation of vehicle movement

With the development of information technology in the last 15 years, numerous software have appeared on the market to simulate the movement of vehicles. The two most famous programs are Vehicle Tracking (Autodesk) [6] and AutoTURN (Transoft Solutions) [10]. These programs are used as additional applications in the interface CAD. The main advantage in computer simulation of vehicle movements is that it is relatively easy and fast to define different types of vehicles with arbitrary dimensions, set different guidance lines and vary the turning angles, and the representation of the trajectory of the vehicle movement is fast and accurate. The distributors of the software available on the market point out that they are not responsible for errors and damage that may occur due to their use. Since the method of computer drawing of the vehicle trajectory is the basis for conducting this research work and the manufacturer did not provide evidence of the accuracy of the software in relation to the actual behavior of the vehicle, an accuracy analysis was conducted for Vehicle Tracking. The results [7] showed that the deviations are greater than the actual measured values on the polygon by a maximum of 14 cm. According to [8], the average deviation between the values obtained by field measurements and those obtained by simulating the vehicle motion in the software Vehicle Tracking is -7 cm. In 95 % of the cases, the simulation resulted in larger widths of the surfaces crossed by the vehicles than the real ones, which should be considered from the point of view of safety design. The results of the T-test [8] showed that with 95 % confidence it can be claimed that there is no difference between the observed variables.

3 Research methodology

To investigate relations between the required widening values, circular arcs with the following radii were selected: 12.5, 25, 45, 75, 120, 150, 175, 250, 350 and 500 m. Research procedure consisted of the following steps:

- determination of road widening in all above mentioned curves for a single lane according to Croatian regulations [1] for the longest vehicles,
- determination of road widening in all above mentioned curves for a single lane road according to German guidelines [2],
- determination of road widening in all above mentioned curves for a single lane according to the software Vehicle Tracking for three design vehicles (three-axle bus, truck with trailer and truck with semi-trailer) and different turning angles from 45 to 270° (Figure 2). During the test vehicles must follow curves shown on Figures 1, 2 with the front left outermost point.
- comparison of results.

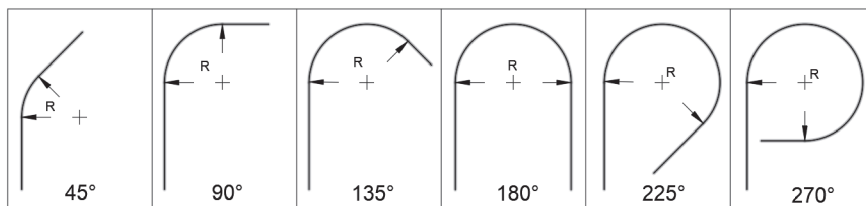


Figure 2 Curves for different turning angles

Three axle bus with a length of 15.0 m from German guidelines [5], a semi-trailer truck with a length of 16.5 m and a truck with a trailer with a length of 18.75 m from Croatian guidelines [4] were selected for testing in Vehicle Tracking software (Figure 3). These vehicles are selected because preliminary tests have shown that a 15.0 m bus is less favorable than an articulated bus, and trucks with a trailer and semi-trailer from Croatian guidelines are less favorable than German ones [5].

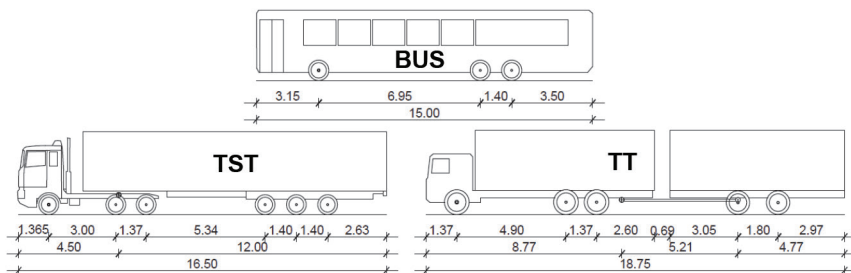


Figure 3 Design vehicles [4]

4 Research results

Research results showed the following (Figures 4, 5, 6, 7):

- eqn (3) gives smaller widening values of compared to eqn (4) and can only be used to determine the widening for a truck with a trailer for radii of curves greater than 25 m,
- eqn (4) gives higher widening values than simulation for both trucks and for all radii of curves greater than 25 m,
- the bus occupies the largest surface width for all radii of curves and all turning angles,
- the largest widening value is required for a turning angle of 270 ° and a circular arc radius of 12.5 m for all design vehicles,
- the influence of turning angles on the required widening values is more significant for radii less than 45 m, ie the higher the turning angle, the greater the widening value is required.

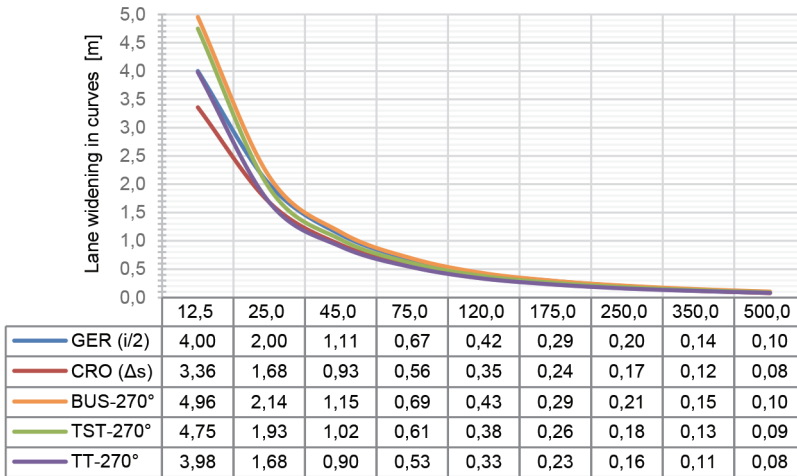


Figure 4 Lane widening according to Croatian regulations [1], German guidelines [2] and software simulation of design vehicles movement

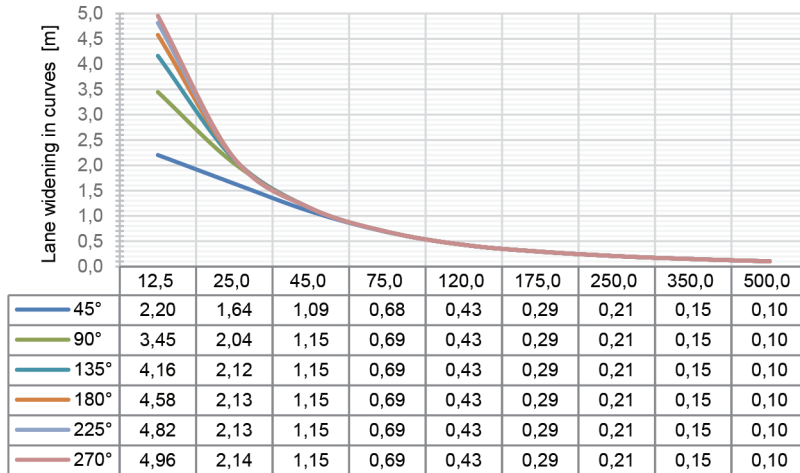


Figure 5 Lane widening in curves for three-axle bus, $l=15,0$ m

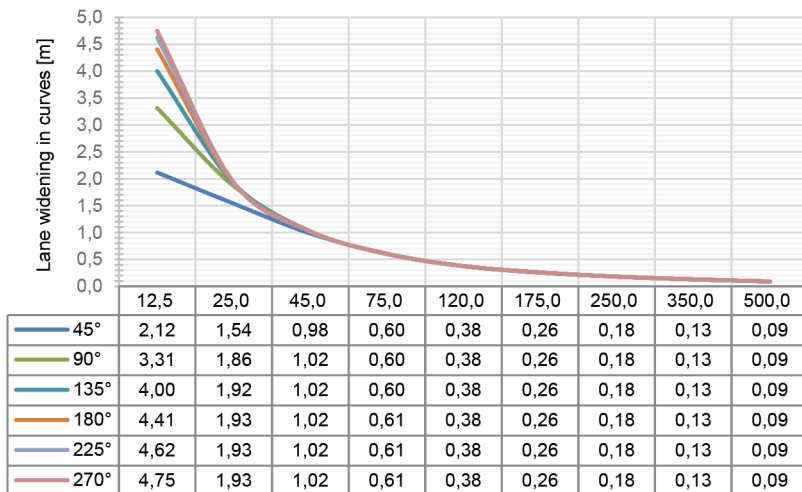


Figure 6 Lane widening in curves for truck with semi-trailer, $l=16.5$ m

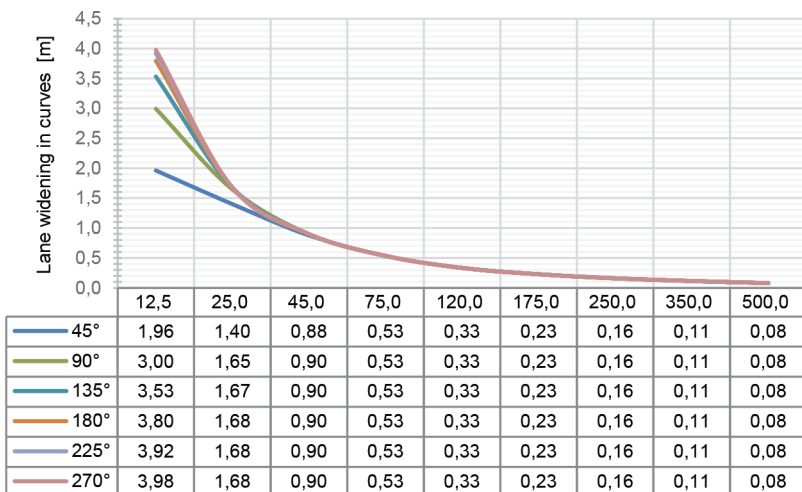


Figure 7 Lane widening in curves for truck with trailer, $l=18.75$ m

5 Conclusions

The research showed that the widening of the road for the longest vehicles according to the German guidelines corresponds better to real vehicle movement than the Croatian regulations. Furthermore, the research shows that when the width of the non-widened roadway is 3.00 m, no widening is required for curve radii greater than 250 m, and when the width of the non-widened roadway is 3.50 m, no widening is required for radii greater than 120 m either. For curve radii smaller than 45 m, the widening must be determined based on the vehicle movement trajectories due to the high influence of the turning angle on the required size of the widening. All these facts indicate the need to update the existing regulations and guidelines in this respect.

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