CETRA²⁰¹²

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

Road and Rail Infrastructure II

Stjepan Lakušić – EDITOR

Proceedings of the
2nd International Conference on Road and Rail Infrastructures – CETRA 2012
7–9 May 2012, Dubrovnik, Croatia

Road and Rail Infrastructure II

EDITOR
Stjepan Lakušić
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Zagreb, Croatia

ORGANISATION

CHAIRMEN

Prof. Željko Korlaet, University of Zagreb, Faculty of Civil Engineering
Prof. Stjepan Lakušić, University of Zagreb, Faculty of Civil Engineering

ORGANIZING COMMITTEE

Prof. Stjepan Lakušić
Prof. Željko Korlaet
Prof. Vesna Dragčević
Prof. Tatjana Rukavina
Maja Ahac
Ivo Haladin
Saša Ahac
Ivica Stančerić
Josipa Domitrović

All members of CETRA 2012 Conference Organizing Committee are professors and assistants of the Department of Transportation, Faculty of Civil Engineering at University of Zagreb.

INTERNATIONAL ACADEMIC SCIENTIFIC COMMITTEE

Prof. Ronald Blab, Vienna University of Technology, Austria
Prof. Vesna Dragčević, University of Zagreb, Croatia
Prof. Nenad Gucunski, Rutgers University, USA
Prof. Željko Korlaet, University of Zagreb, Croatia
Prof. Zoran Krakutovski, University Sts. Cyril and Methodius, Rep. of Macedonia
Prof. Stjepan Lakušić, University of Zagreb, Croatia
Prof. Dirk Lauwers, Ghent University, Belgium
Prof. Giovanni Longo, University of Trieste, Italy
Prof. Janusz Madejski, Silesian University of Technology, Poland
Prof. Jan Mandula, Technical University of Kosice, Slovakia
Prof. Nencho Nenov, University of Transport in Sofia, Bulgaria
Prof. Athanassios Nikolaides, Aristotle University of Thessaloniki, Greece
Prof. Otto Plašek, Brno University of Technology, Czech Republic
Prof. Christos Pyrgidis, Aristotle University of Thessaloniki, Greece
Prof. Carmen Racanel, Technical University of Bucharest, Romania
Prof. Stefano Ricci, University of Rome, Italy
Prof. Tatjana Rukavina, University of Zagreb, Croatia
Prof. Mirjana Tomičić–Torlaković, Univiversity of Belgrade, Serbia
Prof. Brigita Salaiova, Technical University of Kosice, Slovakia
Prof. Peter Veit, Graz University of Technology, Austria
Prof. Marijan Žura, University of Ljubljana, Slovenia

PAVEMENT WIDENING ON ROAD CURVES

Željko Korlaet[1], Tomislav Dobrica[2], Ivica Stančerić[1]
1 Faculty of Civil Engineering, University of Zagreb, Kačićeva 26, Zagreb, Croatia
2 Croatian Roads, Vončinina 3, Zagreb, Croatia

Abstract

Pavement widening on horizontal curves is necessary in order to ensure enough lateral clearance between two vehicles which are passing each other on the road curve in order to ensure undisturbed traffic flow. Guidelines and regulations of different countries offer different solutions for determining amount of traffic−lane widening on road curves. This paper shows the analysis of Croatian, Austrian, German and Swiss guidelines. Based on this analysis the optimum proposition for determining the required amount of traffic−lane widening on road curves has been offered.

Keywords: pavement widening, curve radius, dimensions of design vehicle,
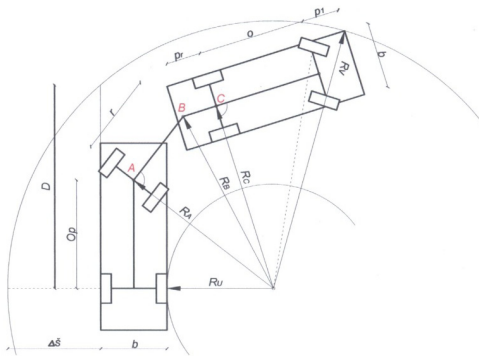   vehicle movement geometry

1   Introduction

Vehicles occupy more traffic−lane space when they are going through the horizontal curve compared to driving on straight road sections, since the back wheels describe smaller radius than the front wheels (Figure 1). That is the reason why it is necessary to widen traffic lanes (pavement) on curves, which depends on two basic parameters: curve radius and design vehicles dimensions. The third parameter on which the widening amount depends refers to the value of turning angle between the entry and exit curve tangent.
This paper provide analysis (comparison) of determining amount of traffic lane widening on curves, for the same characteristics of the curve and the design vehicle, according to the current guidelines of Croatia [1], Austria [2], Germany [3] and Switzerland [4]. The analysis has been limited to the horizontal curves radii R ≥ 45 m, since the radius R = 45 m is the smallest allowed radius on open roads (for the lowest design speed of VP = 40 km/h). Determining the amount of widening for the curves with radii ranging within R = 45−12,5 m (hairpin bends, turning bays, intersections at grade,..) requires additional detailed analysis, due to the influence of vehicle movement geometry on small radii curves.

2   The ratio of 'D' and 'R_V' parameters

It is common that in guidelines different types of the design vehicles relevant for determining the traffic lane widening are defined, ranging from the smallest (passenger car) to the biggest (truck trailer) vehicles. Unfortunately, dimensions of design vehicles in guidelines [1, 2, 3, 4] are not the same, which makes their comparison much more difficult. Thus, the analysis carried out in this study is limited to the biggest design vehicle, truck trailer, for two reasons: first, such vehicles require the biggest widening values which makes the differences more prominent, and second, the dimensions of such vehicles are standardized enough by guidelines since they are tied to the biggest allowed length of 18,75 m adopted on European level.

Figure 1   Illustration of the vehicle movement geometry on the road curve

The common feature of all mentioned guidelines lies in the fact that in the procedure of determining the widening for truck trailer (assembly made of three parts: truck, drawbar and trailer) 'alternative' vehicle is used, the dimensions of which are characterized by the reduced length 'D' (Figure 1). The reasons why 'D' values mutually differ in some guidelines are probably related to the differences in the design vehicle dimensions (axle distance, front overhang, total length,...). One of the aims of this analysis is to test whether the differences in 'D' length influence the widening and to what extent. However, such uniformly determined 'D' length used for 'all' of curve radii is questionable due to the fact that the length 'D' also depends on the radius of the circular arc R_V according to the following formula [5]:

$$D^2 = R_v^2 - \left\{ \sqrt{\left[\sqrt{R_v^2 - (o + p_1)^2} - \frac{b}{2} \right]^2 + p_r^2 - r^2 - o_p^2} + \frac{b}{2} \right\}^2 \qquad (1)$$

According to the formula (1), for the truck trailer L=18,00 m (Figure 2) and different radii R_v in Table 1 'D' values are shown. The truck trailer length of L = 18,00 m was chosen for the reason that truck trailers of the maximum allowed length L= 18,75 m appear very rarely in traffic, so that it is not logical to widen the roads for such exceptionally long vehicles. However, the results shown in the table 1 illustrate that even for the exceptionally small radii of curvature (R_v = 12,5 − 45 m) length 'D' does not achieve the values (Section 3) contained in some guidelines (D = 9,77 m − Austria; D = 10,00 m − Germany; D = 10,00 m − Switzerland)!
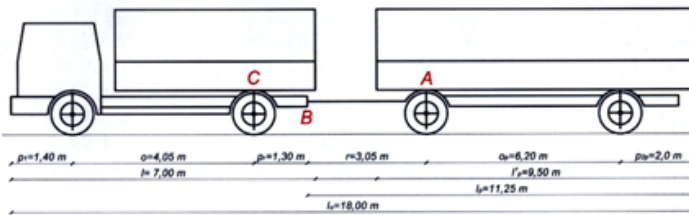
Figure 2   The dimensions of the design vehicle L = 18,00 m

Table 1   'D' values for 'R_v' radii and for the truck trailer L = 18,00 m

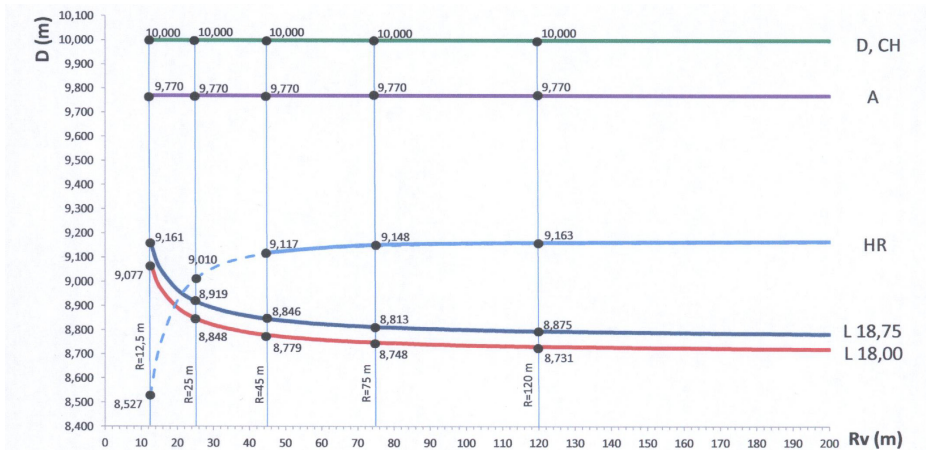| Rv (m)	12,5	15	20	25	30	35	40	45	50	55	60	75	100	120	200
D (m)	9,077	8,980	8,892	8,848	8,821	8,803	8,789	8,779	8,771	8,765	8,759	8,748	8,736	8,731	8,720

Figure 3 Illustration of 'D' values

The diagram in Figure 3 shows 'D' values for the truck trailer of the L = 18,00 m and L= 18,75 m. It is evident from the diagram that the influence of different values of the radius R_v on the 'D' length for the radii $R_v \geq 45$ m is practically negligible, since the differences range within the limits of 6−7 cm, which is less than 1%. The differences in 'D' values for both truck trailers are also negligible (L 18,00 and L 18,75) and they range within the same limits (6−7 cm). Therefore, it can be concluded that 'D' lengths in foreign guidelines [2, 3, 4] are defined according to safety criteria, however the question arises whether such (excessive?) values result in irrationally big values of traffic lane widening?! This problem has been analysed in Section 3 of this paper. Differences in 'D' length become important only for the range of values of the radius $R_v = 12,5 - 45$ m. This area is delicate due to the specificities that result from the laws of (big) vehicle movement geometry in small radii curves.

3 The method of calculating Δš widening and the comparison of results

3.1 Calculation of Δš value [m]

3.1.1 Croatian guidelines
The values of Δš in circular arc for one traffic lane, for the radii R ≥ 45 m and for the vehicle category – truck trailer, is determined according to the formula

$$\Delta a = 42/R \tag{2}$$

where 'R' represents the radius of road axis.

3.1.2 Austrian guidelines
The necessary widening for one traffic lane is calculated by means of the formula:

$$i_{Fst} = (R - \sqrt{R^2 - D^2} + b_{Fz} - b_{Fst}) \cdot p' + S \tag{3}$$

where: 'i_{Fst}' represents traffic lane widening with the safety distance; 'R' – circular arc radius on the road axis; 'D' – reduced vehicle length; 'b_{Fz}' – maximum vehicle width (2,25 m); 'b_{Fst}' – the width of the traffic lane in the direction; 'p' – reduction factor depending on the turning angle 'γ'; 'S' – safety distance (s ≥ 0,25 m on the traffic lane).
$D_{max} = 9,77$ m (for truck trailer)

3.1.3 German guidelines

Pavement widening value 'i' is calculated according to the formula:

$$i = n \cdot (R_a - \sqrt{R_a^2 - D^2}) \tag{4}$$

where: 'D' represents reduced vehicle length; 'R_a' – radius of the exterior pavement edge; 'n' – number of traffic lanes.
D = 10,00 m (for truck trailer)

3.1.4 Swiss guidelines

The necessary traffic lane widening 'e' is calculated according to the formula:

$$e = R_a - \sqrt{R_a^2 - D^2} \tag{5}$$

where: 'D' represents reduced length of the vehicle; 'R_a' is the radius of the exterior pavement edge.
D = 10,00 m (for truck trailer)

3.2 The comparison of calculation methods

If different designations for the widening (i_{Fst}, i, e) and some specificities in Austrian guidelines (b_{Fz}, b_{Fst}, p', s) are disregarded the formulas (3), (4) and (5) are structured in the same way and the widening is calculated according to the formula:

$$\Delta a = R - \sqrt{R^2 - D^2} \tag{6}$$

The same refers to Austrian guidelines which in their approach have initially 'built in' protective widths (the difference $b_{Fz} - b_{Fst}$ and the value S), which in German and Swiss procedures were 'built in' subsequently. The same refers to the reduction factor p', which depends on the turning angle 'γ' and for big turning angles gets the value p' = 1 so it does not influence the widening value Δš. If we exempt these influences from formula (3), it takes the form of formula (6) which allows for the realistic comparison of values (A1 in Figure 4.) with the values of other guidelines and other calculations of the value Δš shown in Figure 4. The formula in Croatian guidelines (2) has been modified for the same reason (the possibility of comparison), due to the fact that it is the only one which is not initially based on the reduced vehicle length 'D'. By equalizing formulas (2) and (6)

$$42/R = R - \sqrt{R^2 - D^2}$$

and rearranging this equation we obtain the formula for the calculation of the reduced vehicle length 'D' depending on the radius 'R' in accordance with the method of setting the widening according to Croatian guidelines:

$$D = \sqrt{84 - \frac{42^2}{R^2}} \tag{7}$$

Based on formula (7) values 'D' for different values of the radius 'R' have been calculated and plotted in the graph in Figure 3. The chart makes evident that the influence of different values of the radius on 'D' length for the radii R ≥ 45 m is practically negligible since the differences range within the limits up to 5 cm. For the values of the radius R < 45 m (up to R = 12,5 m) the differences in 'D' length (dashed part of the curve) become big, but that fact is irrelevant for this study, especially because the guidelines explicitly emphasize that determining widening values Δš according to the formula (2) refers only to the radii R ≥ 45 m. The values of the length 'D' range around 9,15 m and are significantly lower than the values in Austrian (D = 9,77 m), German and Swiss (D = 10,00 m) guidelines.

3.3 The results of the calculation of maximum widening values

For all methods of widening calculation values Δš (m) have been shown in Figure 4 for curve radii R = 25, 45, 75 and 120 m. The selected radii values refer to the minimum allowed radii of horizontal curves for the corresponding values of design speed (V_p = 30, 40, 50 and 60 km/h) according to Croatian guidelines.
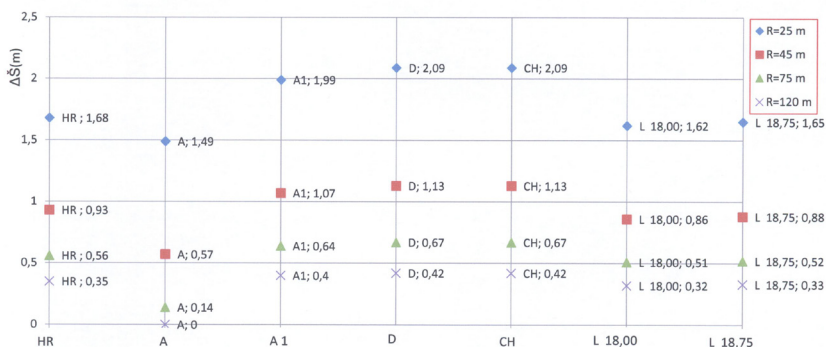

Figure 4   Widening values Δš (m)

4 Conclusion

4.1 Comparison of values Δš

The insight into the results shown in Figure 4 leads to the following features:
· as expected, widening values are the highest in German (D) and Swiss (CH) guidelines, owing to the biggest reduced length 'D' of 10,00 m;
· Austrian (A) regulations have the lowest values owing to the earlier described approach to calculation (the protective width). The shown values are determined for the traffic lane width of 3,00 m. The column A1 shows the values for Austrian guidelines (D = 9,77 m) without the 'addition' according to formula (6), which are higher by app 0,5 m from the values in column A and are expectedly lower than D and CH values due to the shorter reduced length of D=9.77 m.
· exact values of widening (L 18,00 i L 18,75) calculated for the real vehicles according to formulas (1) and (6) give the lowest values (with the exception of the value according to (A) – see the former explanation). The differences between L 18,00 and L 18,75 are negligibly small;
· results of Croatian guidelines (HR) are sort of 'surprise' with regard to the original formula (2) which does not contain the value 'D' as a relevant value for determining widening values, and the values are identical to those obtained through formulas (7) and (6). The obtained values (HR) are practically the same as the exact values for L 18,00 m and L 18,75.
On the basis of the above it follows that the calculation method according to Croatian guidelines is the optimum solution.
That is for two reasons:
· the formula (Δš = 42/R) is the simplest one;
· the values of widening are the closest to the exact values (L 18,00 and L 18,75) for real vehicles.

This conclusion is not less relevant regardless the established (?!) arguments that the values of the German (ᴅ) and Swiss (ᴄʜ) guidelines are concerned with safety, which for the illustrated radius range R = 25–120 m are bigger for the amount of 0,41 m (R = 25 m) do 0,07 m (R = 120 m).

4.2 Reduced values Δš (the influence of the turning angle)

All mentioned guidelines contain the obligation of checking the influence of the turning angle on the necessity of reduction of Δš values determined according to the illustration in Section 3 of this paper. This obligation is based on the laws of vehicle movement geometry, which become more pronounced with the decrease in the values of the curve radius. Testing the need for the reduction of the amount of widening in this work is limited to the radius values ʀ ≥ 45 m.
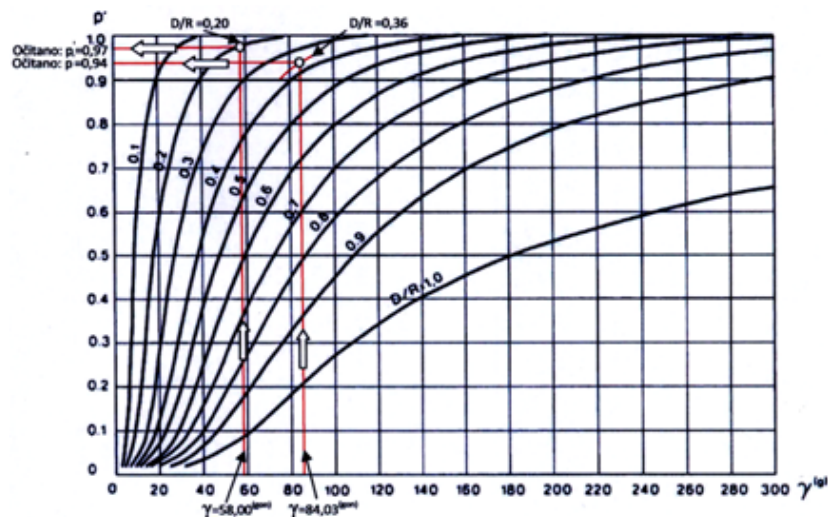

Figure 5   Determining the reduction factor

The limited range of this paper allows neither the more detailed explanation of the influence of the turning angle on the reduction of widening value Δš nor the precise illustration of the procedures involved in individual guidelines. Since the approach in foreign guidelines is basically very similar, in this analysis the used verification method is taken from Austrian [2] and Swiss [4] guidelines, according to which it is necessary to reduce the widening value if the specific turning angle   (the central angle of the curve, i.e. the angle at which the tangents of the curve cross) is smaller than the minimum allowable intersection angle determined by the formula [4]:

$$\Phi limit = 5,5 \ arcsin \ (D/R)$$

The need for reduction is in Austrian and Swiss guidelines determined on the basis of the chart shown in Figure 5 by setting the reduction factor 'p' depending on the values of the turning angle 'γ' and the relationship between parameters 'D/R'.
Croatian guidelines do not contain the reduction factor but there is a provision that for the radii R = 25–45 m the widening can still be determined as for the radii ʀ ≥ 45 m, if the turning angle of the curve is › 90°, while for the radii ʀ ‹ 25 m the widening must be determined according to the provisions for hairpin bends. Whether and to what extent such provision corresponds to the real situation was tested on two specific examples of calculation of the turning angle 'γ' for boundary cases permitted by guidelines [1] for the radii R = 45 m and R

= 25 m. For the set value of the radius the smallest real turning angle 'γ' is determined by the minimum allowed length of the transition curve L_{min} (graph 3.2 [1]) and by minimum allowed length of circular arc L_{Kmin} (Table 3.2 [1]):

R = 45 m L_{min} = 30 m L_{Kmin} = 11 m   →'γ'= 58,00(g)
R = 25 m L_{min} = 25 m L_{Kmin} = 8 m   →'γ'= 84,03(g)

To use the graph in Figure 5 i.e. to determine the reduction factor 'p' it is necessary to set the relationship D/R, where the reduced lengths 'D' were used, which were for Croatian guidelines determined by the curve 'HR' in the graph in Figure 3.:

R = 45 m   D = 9,117 m   D/R = 0,20   →p' = 0,97
R = 25 m   D = 9,010 m   D/R = 0,36   →p' = 0,94

On the basis of the above it follows that, if the designer adheres to the provisions of the guidelines [1] which refer to the application of values L_{min} i L_{Kmin}, for the radius R = 45 m there is no need for reduction (the application of higher values $L › L_{min}$ i $L_K › L_{Kmin}$ results in the increase of the turning angle), since the reduction factor is p' ≈ 1.
Practically the same is true for the radii R = 45 − 25 m, by which the 'limitation' contained in the regulations that the widening can be determined according to the formula (2) only if the turning angle is at least 90° (100g) becomes redundant.

References

[1]   Book of regulations on the basic conditions which public roads outside settlements and their elements must fulfill from the standpoint of traffic, Narodne novine br.110/01, Zagreb, 2001.

[2]   Richtlinien und Vorschriften für den Straßenbau, RVS 3.23. Trassierung, Linienführung, 8.4. Fahrflächenverbreiterung im Bogen, Wien, 1997.

[3]   Richtlinien für die Anlage von Straßen, Teil: Linienführung, RAS-L 7.5. Fahrbahnverbreiterung in der Kurve, Bonn, 1995.

[4]   Schweizer Norm SN 640 105b, Verbreiterung der Fahrbahn in Kurven, Zürich, 2003.

[5]   Korlaet Ž., Vehicle movement geometry as the criterion for forming road traffic surfaces, Master's thesis, The Faculty of Civil Engineering of the University of Zagreb, Zagreb, 1981.