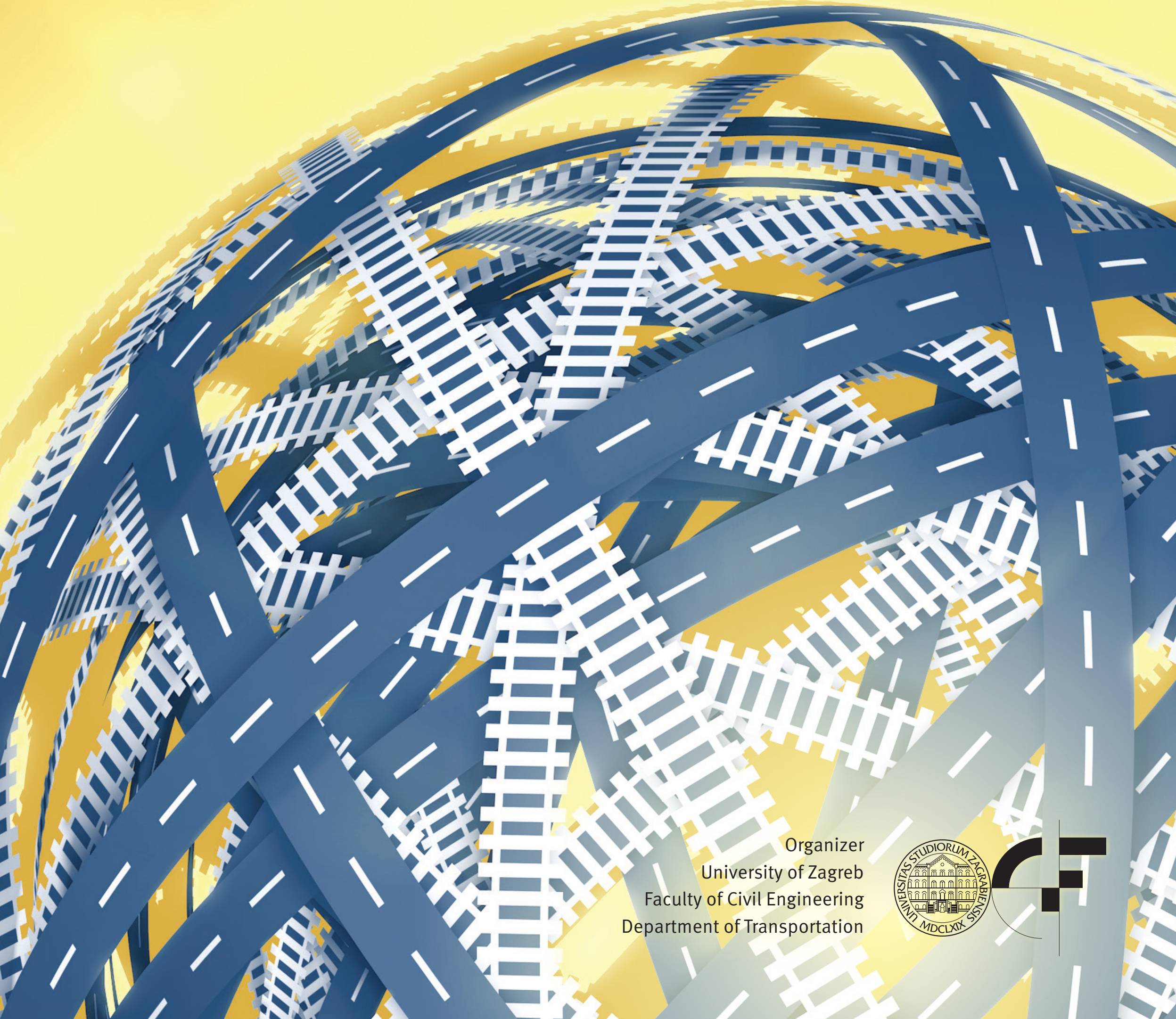
CETRA[2016]

4th International Conference on Road and Rail Infrastructure
23–25 May 2016, Šibenik, Croatia

Road and Rail Infrastructure IV

Stjepan Lakušić – EDITOR



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Road and Rail Infrastructure IV

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ANALYSIS OF SOLUTIONS FOR SUPERELEVATION DESIGN FROM THE STANDPOINT OF EFFICIENT DRAINAGE

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Abstract

The determination of pavement cross slope is integral part of geometric design of roads. It is performed due to reasons of driving dynamics i.e. to ensure lateral stability of vehicle in a curve and also to assure optimal drainage of pavement. Empirical knowledge, incorporated in guidelines for road design in many countries, indicate that the minimum value of cross slope to ensure sufficient drainage is 2.5%, which is also common value on the tangent parts of the road. The problem occurs on parts of the route between the opposite curves in which, due to the need for change in cross slope direction, the cross slope ranges from 0-2.5%. A particular problem occurs on parts of the route with (too) small longitudinal gradient, which does not ensure efficient drainage in the longitudinal direction.
The subject of this paper is analysis of options for superelevation design in a number of countries (CRO, D, A, CH, UK, USA, AUS), and a critical comparison of available solutions, considering the criteria of efficiency or optimization of pavement drainage.

Keywords: superelevation, geometric design, sufficient drainage

1 Introduction

Road design should be carried out with the goal of safe and comfortable ride on a given road. Pavement cross slope is an element of a geometric design, performed for lateral stability of vehicle in a curve and to assure unobstructed drainage of pavement. Minimum cross slope of 2.5%, conditioned by optimal pavement drainage, is also the most frequently used value in the tangent (varies according to guidelines from 2-3%). Rotation of one-sided cross slope from one direction to another inevitably passes through the zone with cross falls smaller than 2.5% (0%). In combination with very small and insufficient longitudinal gradient, it leads to accumulation of water film on the road surface which can have significant consequences for traffic safety: reducing the adhesion between the road surface and tires, loss of vehicle stability, water splashes and reduced visibility, and at high speeds occurrence of hydroplaning.

2 Possibilities for superelevation design

Guidelines of certain countries contain mostly the same or similar standardized superelevation designs, which differ according to the axis of roadway rotation, location of superelevation transition and the type of cross section that is applied in tangent (one sided, crowned). Along prescribed solutions for superelevation design, some guidelines identify drainage problems of superelevation development in reverse curves so they prescribe restriction of longitudinal gradient, the intensification of rate of rotation in the zone with no slopes (plateaus) and, in different versions, superelevation design with diagonal crown.

2.1 Croatia [1]

In Croatian guidelines superelevation development should be carried out within the transition curve, rotating roadway around its centerline or its lower edge in roads with only one roadway, or around the centerline or the edge of the median in roads with two roadways. The layout of superelevation development is defined by superelevation transition gradient, and its maximum values are defined in relation to the design speed and the width of the roadway. The minimum rates of gradient are limited due to sufficient drainage of pavement in areas of change of cross slope orientation, which includes 0% cross slope. In the case where the rate of rotation is less than the minimum, it should be intensified by using minimal value from the inflection point until achieving cross-slope of 2.5%, followed by rate that is less than minimal because the drainage is provided by achieved cross slope (Fig. 1). In these areas it is recommended that longitudinal gradient is 0.3% (preferably 0.5%) higher than the rotation rate in order to improve the drainage conditions.

2.2 Germany [2,3]

According to German guidelines superelevation development should also be carried out on the length of transition curve, and centerline of road or of a particular roadway is preferred for the axis of pavement rotation, but if necessary internal or external edge of the road can be used (Fig. 1). Limits of superelevation transition gradient depend on the road category and pavement widths. When the gradient is less than the minimal, in areas where cross slope orientation changes, the minimum value should be adopted in the section between -2.5% and + 2.5%. The longitudinal gradient of pavement edges and road centerline should be aligned to avoid adverse slopes and their differences should be a minimum of 0.2%. It is therefore recommended that minimum longitudinal gradient of road centerline is greater than or equal to 1.0% (exceptionally 0.7%), while the longitudinal gradient of the pavement edge should be greater than or equal to 0.5% (exceptionally 0.2%). In the absence of the required longitudinal gradient, 0% cross fall can be relocated away from the inflection point of reverse curves.

2.3 Austria [4]

In Austrian guidelines superelevation development is performed on the length of transition curves, including short tangents in between, but guidelines show only pavement rotation along roadway centerline (Fig. 1). Limit values of superelevation transition gradient are defined according to the width between rotation axis and roadway edge. Where the superelevation transition gradient is less than the minimum and there is no longitudinal gradient, a minimum value should be used until cross slope of 2.5% is reached while the rest of superelevation transition has gradients less than minimal, or diagonal crown can be used. Diagonal crown is recommended for insufficient longitudinal gradients because cross fall of entire section is 2.5% (Fig. 2a).

2.4 Switzerland [5]

Swiss guidelines emphasize the need for careful superelevation design because of the possible consequences on the safety, related to the lateral run-off on pavements, the optical guidance and sudden changes in lateral acceleration that are not compensated by transverse slope. Superelevation development is performed on the length of the transition curve, while selection of the rotation axis depends on cross slope, pavement rotation rate and position of road in road network. When the superelevation transition gradient is less than the minimum allowed, it is necessary to carry out intensified superelevation development or diagonal crown. Diagonal crown is necessary at high speed roads where the diagonal slope is less than

0.5%. It is carried out until 3% cross fall (Fig. 2b) and its length depends on the speed and width of the roadway.

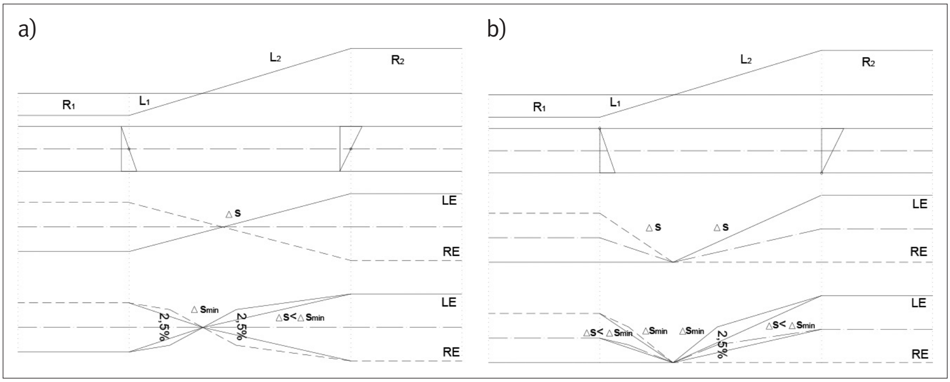

Figure 1 Reverse curves superelevation design: a) around pavement centerline (CRO, D, A) and b) around pavement edge (CRO, D)

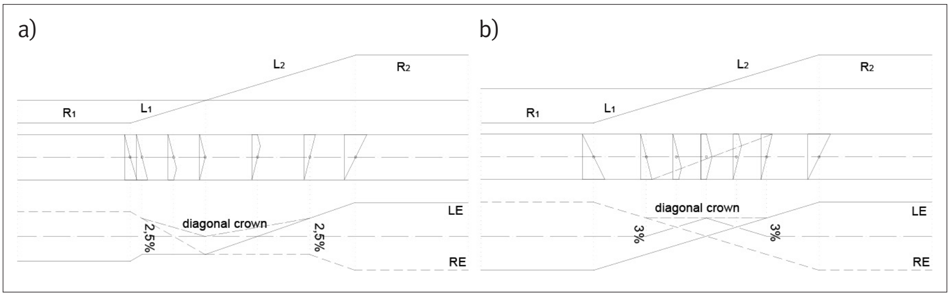

Figure 2 Diagonal crown according to a) A i b) CH

2.5 United Kingdom [6]

Superelevation development should be performed on the length of the transition curve, or when missing, partially on the tangent (1/2 to 2/3 of development length) and the rest on the arc. Guidelines do not define necessary type of superelevation design nor do they define around which axis it should be carried out. However, some conditions related to the drainage and driving dynamics are listed: superelevation development may not be performed so gradually to create plateaus or so sharply to cause driver discomfort from the kink in edges of the roadway. Therefore, the difference of gradient of rotation axis and the edge of the pavement should not be greater than 1% (0.5% on motorways) and all changes in edge profile should be smoothed. In areas of superelevation transition longitudinal gradient should not be less than 0.5%. In case of problems with drainage, solution should be found in changes to horizontal alignment, increased rate of pavement rotation, or application of the diagonal crown.

2.6 United States of America [7]

In the United States commonly applied is crowned cross section, therefore superelevation design consists of two parts: tangent runout and superelevation runoff (Fig. 3). Tangent runout is rotation of part of the roadway (single lane) with cross slope of opposite direction than those in curve, until 0% is reached. Superelevation runoff represents rotation of part of the roadway with 0% cross slope to achieve a one-sided slope for the whole width of the roadway and further simultaneous rotation to the necessary superelevation in curve. Application of transition curve is not obligatory, and if it is not applied, superelevation development takes place partly in the tangent (60-90% of development length) and the rest in the curve. Superelevation development can be made around centerline, inner or outer edge of the roadway with crowned cross section, while in the application of one-sided cross fall the rotation axis should be outer edge of the roadway. In order to avoid problems with drainage in the area of superelevation development, recommendation is that longitudinal gradient of at least 0.5% is provided for centerline and 0.2% for pavement edge.

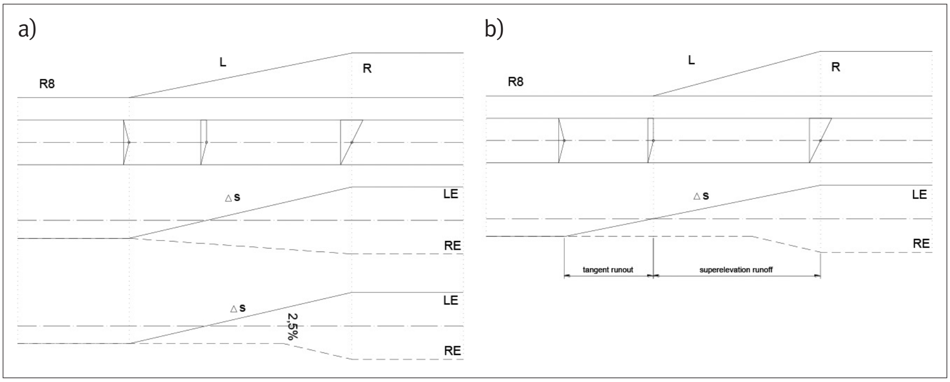

Figure 3 Superelevation design from crowned cross section on tangent to one-sided cross section on curve a) D i CH te b) USA

2.7 Australia [8]

Since in Australia mostly applied on tangent is crowned cross section, superelevation design, as in the United States, consists of tangent runout and superelevation runoff. Between two curves a minimal length of tangent and crowned cross section should be ensured. For better drainage it is recommended to rotate pavement around its inner edge and longitudinal gradient of the pavement edge should be at least 0.2-0.3%. Areas near inflection of reverse curves must not coincide with 0% longitudinal gradient, and possible occurrence of the plateau should be checked by contour plan.

3 Comparison of characteristic examples of superelevation designs

Comparison was carried out for five characteristic superelevation designs, which effectively "cover" or represent all of the examples mentioned in Chapter 2 (Fig. 4).
Selected examples were analyzed for the road category 3-d [1], same design conditions (reverse curves without tangent section, radii R1 = R2 = 250m with transition curves L1 = L2 = 100m and longitudinal gradient of 0.1%) and cross section elements (roadway width 7.10 m, superelevation in curve of 7%). Obtained contour plans with equidistance of 20mm for the area around the inflection point are shown in Fig. 5.
On models of considered superelevation designs it is possible to observe the plateau areas, or areas with very small transverse slopes which retain water. By analyzing modelled superelevation designs it is evident that at conventional superelevation design around centerline (example 1) region with small cross slope extends to largest area around the inflection point, and similar situation happens with superelevation design around pavement edge (example 3). Superelevation design around axis intensified by Δs_{min} (example 2) is more suitable so-

lution, because the area of small cross slopes is reduced, but is still present. In superelevation design with crowned cross section on tangents (Example 4) plateaus are shifted away from the inflection point and limited to a particular lane, because lanes are rotated as two independent surfaces. From the standpoint of drainage, a favourable feature of this solution is narrower surface (one lane) and the shorter runoff length, because the second lane has sufficient cross slope. With diagonal crown (example 5), the formation of the plateaus does not happen and cross slope is always at least minimal 2.5%. Also, it is obvious that in areas where plateaus would be created with conventional superelevation design, runoff lengths achieved here are approximate to those on tangents with one-sided cross slope.

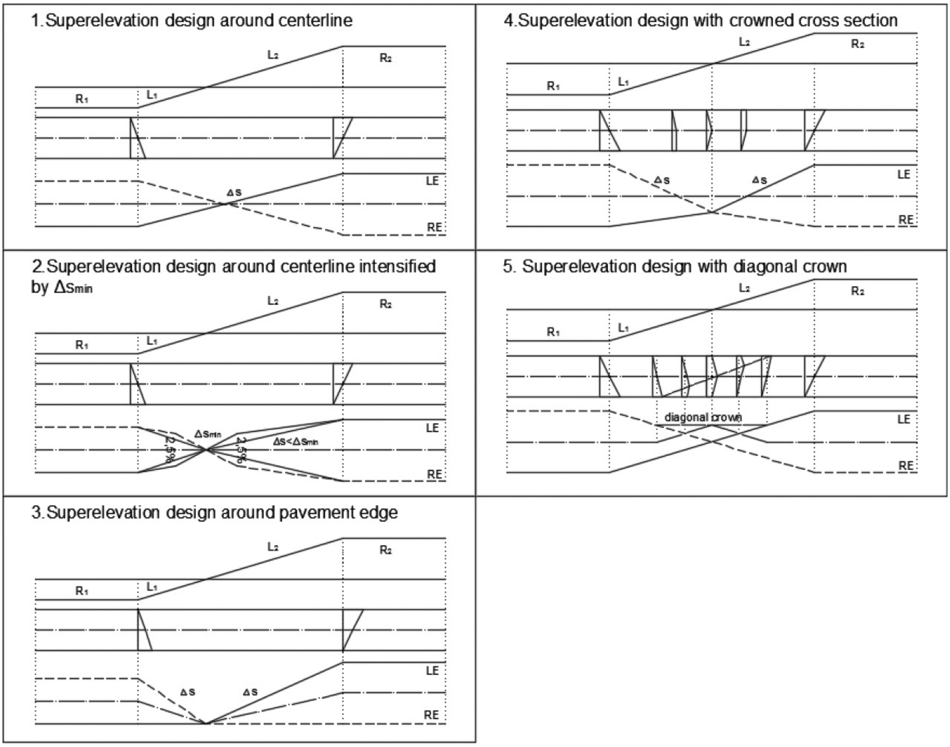

Figure 4 Characteristic superelevation design schemes

Although diagonal crown proved to be the best from drainage standpoint, it contains some unresolved issues and problems related to driving dynamics. Crossing the diagonal crown causes the impact of vehicle on ridge and results in vertical and radial acceleration, which can cause discomfort and adversely affect safety. For this reason it is necessary to smooth the ridge with a certain radius (such as prescribed by guidelines [4]). In addition, the right pair of wheels drive on the oppositely oriented cross slopes in relation to the center of curvature, which further aggravates the widely accepted rules of lateral stability of vehicle in a curve, or the interdependence of the value of cross fall, radius and radial friction coefficient. This problem is also present in designs with crowned cross sections (Example 4), although it is less pronounced since adverse slopes occur on areas closer to the inflection point, where the curvature of transition curve is relatively small. Design with diagonal crown is also unfavourable from construction point of view, because the exact designed geometry is very complicated to perform, and even harder to maintain (in reconstructions).

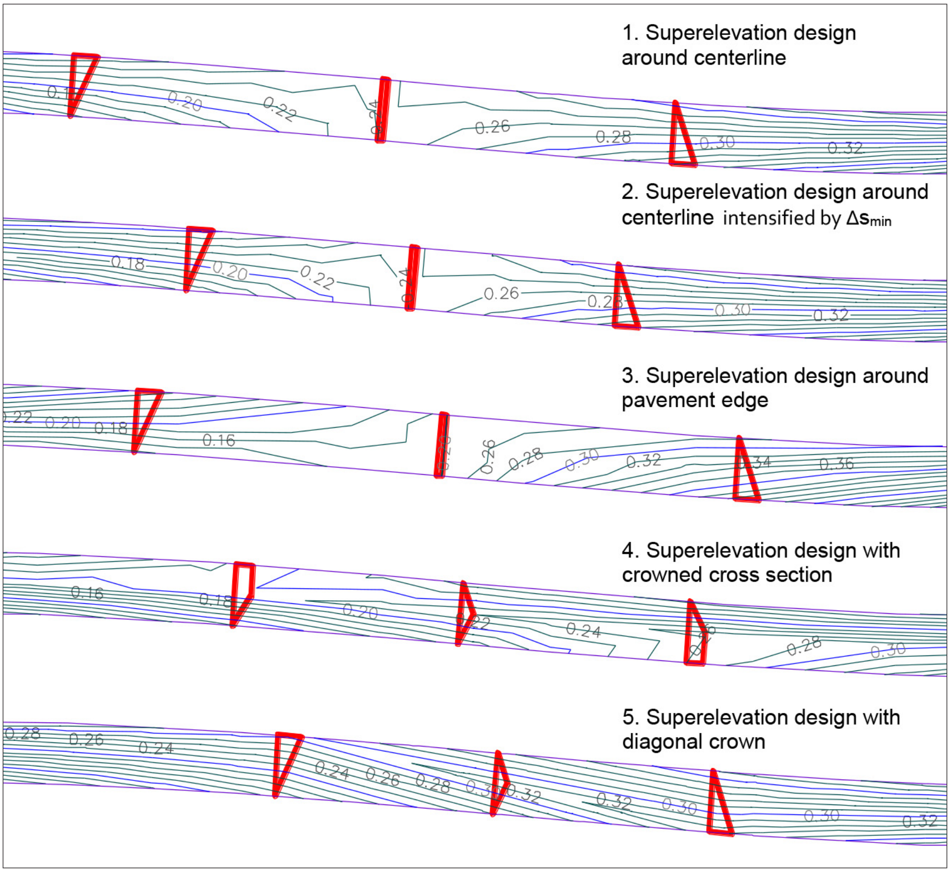

Figure 5 Contour plans of modelled superelevation designs

4 Conclusion

Based on the analysis carried out in Chapter 3, it is clear that the designer is not in an enviable position when searching for the optimal solution. Initially, he is obliged to respect the recommendation of avoiding concurrence of inflection points in horizontal alignment with vertical alignment without longitudinal gradient (flat vertical alignment, the apex of the convex and especially concave vertical curves). Next limitation is respecting the minimum longitudinal gradient, and here a problem is produced because the recommendations in this regard differ, and also considering the fact that the increase of longitudinal gradient accelerates the runoff speed, but increases runoff length and final thickness of water film. The next decision relates to shortening the area with unfavorable cross slopes smaller than 2.5%, applying the Δs_{min}, which ultimately favors a solution in example 2 ahead of solutions in examples 1 and 3. The decision to apply superelevation design with crowned cross section (example 4) or diagonal crown (example 5), should be well thought over, bearing in mind the difficulties of implementation and maintenance of these solutions.

Limit of the paper volume is the reason that this does not show solutions that actually (transverse slotted drains [9], etc.) or at least partially (pavement grooves [10], grinding [11], etc.) enhance the efficiency of the pavement drainage on superelevation development areas with insufficient cross slopes. It should be noted that the implementation of such solutions is generally expensive, and maintenance costs of some do not justify their widespread application. Since the phenomenon of aquaplaning is directly related to the driving speed, for the necessary driving safety on the roads remaining is the measure of limiting speed in adverse weather conditions, whether it is conducted by authorized institution and (or) each driver individually.

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