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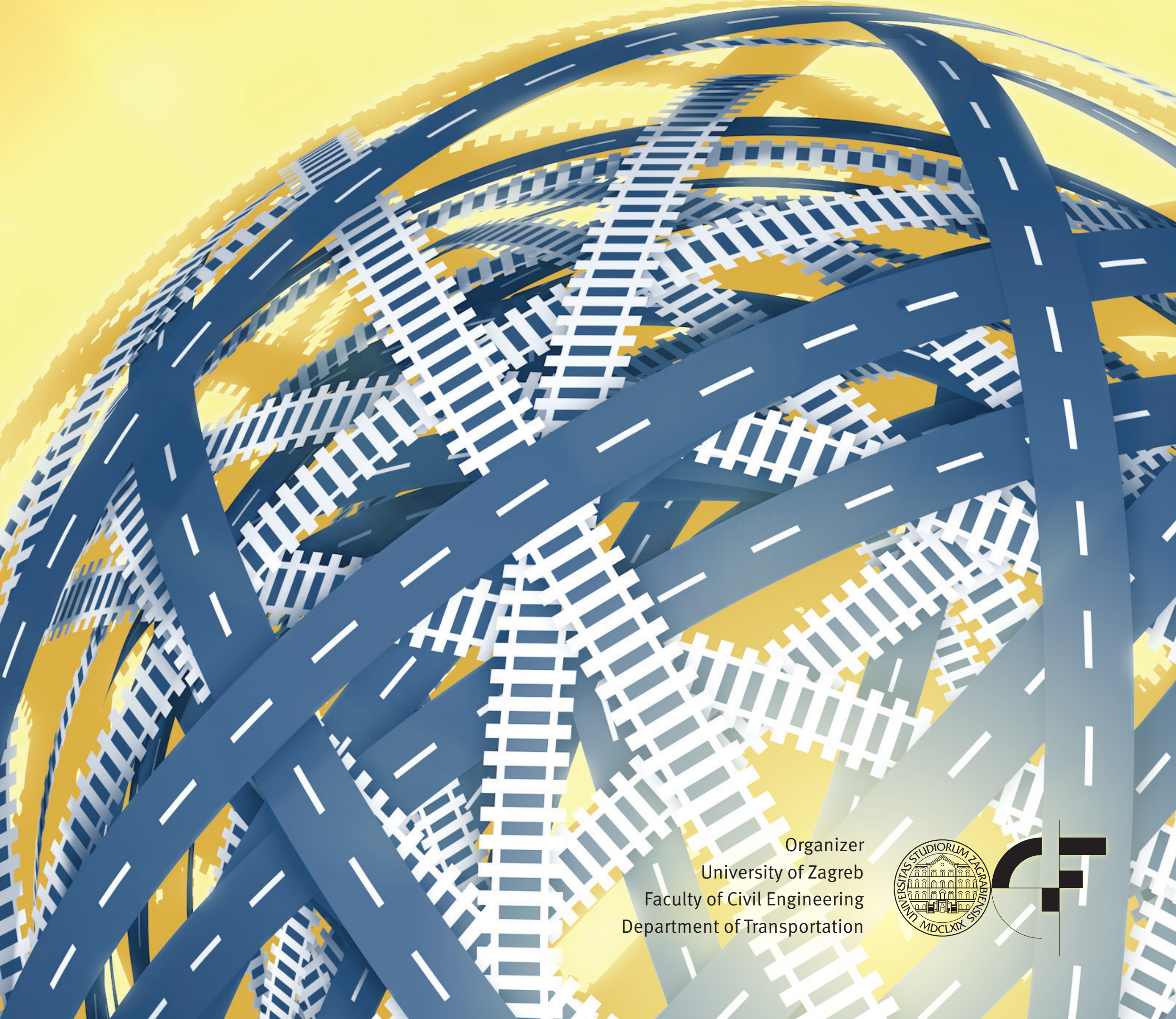
4th International Conference on Road and Rail Infrastructure
23–25 May 2016, Šibenik, Croatia

Road and Rail Infrastructure IV

Stjepan Lakušić – EDITOR



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Road and Rail Infrastructure IV

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PROBLEMS OF CROSSFALL CHANGEOVER FOR REVERSED CROSSFALLS

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Abstract

Crossfall of the carriageway is generally oriented to one side and changing is implemented in principle over the entire length of the transition curve. In the case where crossfalls are reversed, this changeover section is potentially dangerous for aquaplaning (safety problem especially for high speeds). The main parameter for this analysis, relative grade Δs [%], is the difference between the longitudinal gradient along the edge of the carriageway and the longitudinal gradient along the axis of rotation ($\Delta s \geq \Delta s_{min}$). Guidelines and regulations of different countries offer some standard solutions for design of these critical zones, but there are also some differences and special solutions (wedge-like crossfall changing – inclined superelevation). This paper shows the analysis of Bosnian and Herzegovinian, Croatian, Serbian, Austrian, German, Swiss and TEM guidelines.

Keywords: crossfall changeover, relative grade of the edge, aquaplaning, wedge-like crossfall changing

1 Introduction

Presence of water on the carriageway surface causes a very high number of traffic accidents. For that reason, carriageways on straights are designed with a one-sided crossfall q of at least 2.5 % to the outside. For reasons of vehicle dynamics, circular curves are generally designed with a crossfall towards the inside of the circular curve.
The crossfall of a carriageway is changed over a road section known as the superelevation development section. The superelevation development (or rotation of the pavement) generally takes place within the transition curve, regardless of the axis around which the roadway is rotated (Figure 1).

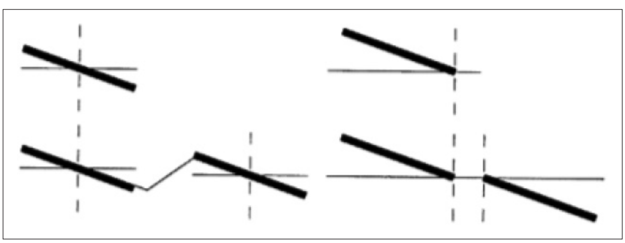

Figure 1 Types of superelevation development [1]

For high driving speeds even a low water film thickness is potentially dangerous for aquaplaning. This problem is especially evident in the zones where crossfalls are reversed and even more for low grades.

For these reasons it is necessary to provide sufficient longitudinal grade of the road (vertical alignment) and ramp of superelevation development. These problems are most pronounced at high speeds and therefore the focus continues to be on them (Motorways with speed V ≥120 km/h).

2 Problem of crossfall changeover

The basic parameters that must be ensured for a superelevation development section are vehicle dynamics and drainage conditions, and these parameters are in conflict.
The main parameter for this analysis, relative grade Δs [%], is the difference between the longitudinal gradient along the edge of the carriageway and the longitudinal gradient along the axis of rotation. In Swiss guidelines its symbol is i and in Serbian i_{RV} (in others also Δs). It is calculated as follows [1]:

$$\Delta s = \frac{q_1 - q_2}{L_V} \cdot a \quad (1)$$

Where:
q_1 [%] – crossfall at the end of the superelevation development section,
q_2 [%] – crossfall at the start of the superelevation development section,
L_v [m] – superelevation development length,
a [m] – distance between the edge of the carriageway and the rotation axis.

To ensure the drainage and vehicle dynamics conditions, Δs should be:

$$\Delta s_{min} \leq \Delta s \leq \Delta s_{max} \quad (2)$$

The minimum value for drainage is as follows:

$$\Delta s_{min} = k_v \cdot a \quad (3)$$

Where:
k_v [%/m] – coefficient of the superelevation development that provides drainage.

The maximum value (vehicle dynamics condition) Δs_{max} depends on the design speed. A sufficient longitudinal grade of the vertical axis should also be provided, taking into account the requirements of superelevation development. Low longitudinal grades in this section are problematic due to slow runoff (Figure 2). The problem is also on vertical curves if this zone is in the vicinity of curve crown.

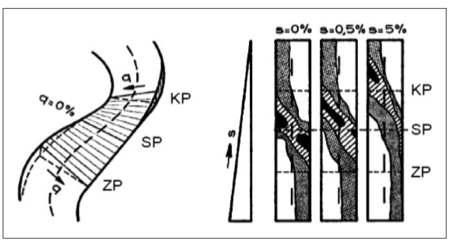

Figure 2 The influence of slope on runoff [3]

In the case where the crossfalls are reversed, minimal longitudinal grade of vertical axis is usually [1], [2]:

$$i_{min} = \Delta s + 0.3\% \quad (4)$$

In cases of low longitudinal grade, some guidelines give “a special” solution as inclined superelevation shown in Figure 3.

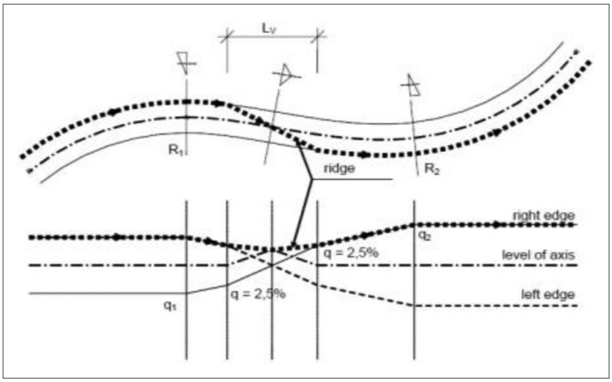

Figure 3 Inclined superelevation [1]

3 Crossfall changeover according to different guidelines

The above mentioned problem of superelevation development is most evident at high speeds. A minimum and maximum value of relative grade Δs are very close and at the same time there is a conflict between vehicle dynamics and drainage problem. Also, there is a problem for low longitudinal grade of vertical axis. Different guidelines offer some standard solutions for design, but there are also some differences and special solutions (wedge-like crossfall changing, inclined superelevation). This chapter shows the analysis in Bosnian and Herzegovinian, Croatian, Serbian, Austrian, German, Swiss and TEM guidelines.

3.1 The minimum relative grade Δs_{min} – drainage condition

According to the above-mentioned guidelines and equation (3), the minimum value for drainage is $\Delta s_{min} = k_v \cdot a$. This coefficient k_v is 0.1 in all guidelines. Only Bosnian and Herzegovinian guidelines [1] give a possibility of $k_v = 0.06$ (even 0.03), “because the value 0.1 causes “flapping” of the carriageway and special design measures shall be provided in this area”. For the case where $\Delta s < \Delta s_{min}$, there are the basic principles of polygonal ramps. This critical zone for aquaplaning has the relative grade Δs_{min} up to the crossfall of 2.5 %, and second ramp grade is not essential. These principles are the same in all the guidelines (shown in Figure 4.).

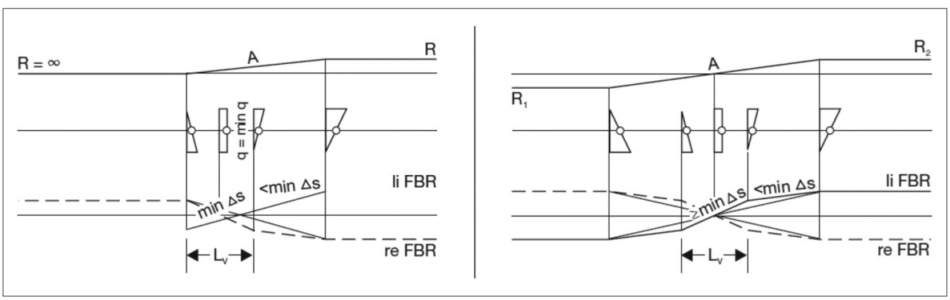

Figure 4 Principles of ramps design [7].

3.2 The maximum relative grade Δs_{max} – driving dynamics and aesthetics conditions

There are different values for maximum relative grade Δs_{max} (shown in Table 1).

Table 1 Values of maximum relative grade Δs_{max}

	V (km/h)			
Guidelines	**80**	**90**	**100**	**>100**
BiH [1] (n=num. of lanes)	1.05 · n	0.75 · n	0.50 · n	0.40 · n
Croatian [2]	1.00	1.00	0.80	0.80
Serbian [3]	1.00	1.00	0.90	0.90
Austrian [4]	–	–	–	–
German [7]	1.00	1.00	0.90	0.90
Swiss [8]	0.75	0.75	0.75	0.75

Austrian guidelines do not give explicit values. Values of Δs_{max} and Δs_{min} are very close for high speeds (same for the highest).

4 Special design measures – Inclined superelevation

As discussed in Chapter 2, there is a problem of slow runoff water from the road surface in the area of small crossfall, especially in combination with small longitudinal grade of the roadway (Figure 2). Some guidelines give inclined superelevation, and some do not. Croatian guidelines do not have inclined superelevation, while B&H guidelines provide it only for speeds less than 80 km/h (in practice it is almost unnecessary for these speeds). Other previously mentioned guidelines allow inclined superelevation.

4.1 Bosnian and Herzegovinian guidelines

These guidelines allow inclined superelevation for speeds V ≤ 80 km/h (Figure 5).
The minimum superelevation development length is calculated as follows:

$$L_v = 0.1 \cdot B \cdot V \tag{5}$$

Where:
L_v [m] – length of inclined superelevation section,
B [m] – width of the carriageway,
V [km/h] – conceptual design speed.

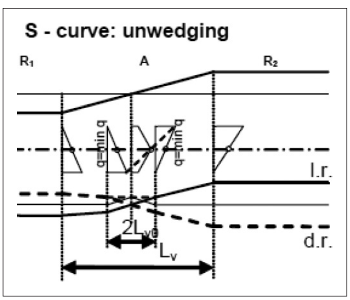

Figure 5 Inclined superelevation in B&H guidelines [1]

4.2 Serbian guidelines

Serbian guidelines have inclined superelevation for all speed and give the minimum length calculation as B&H (5). Minimum lengths of inclined superelevation sections are given in Table 2. The guidelines do not recommend them for speeds V>100 km/h because of the disjointed slope.

Table 2 Length of inclined superelevation L_k section [3]

V_p [km/h]	50	60	70	80	90	90	100	110	120	130
L_k [%]	–	40	50	60	70	80	100	125	135	150

4.3 Austrian guidelines

Austrian guidelines allow inclined superelevation for all speed and give the minimum length as 7 · carriageway width (Figure 6).

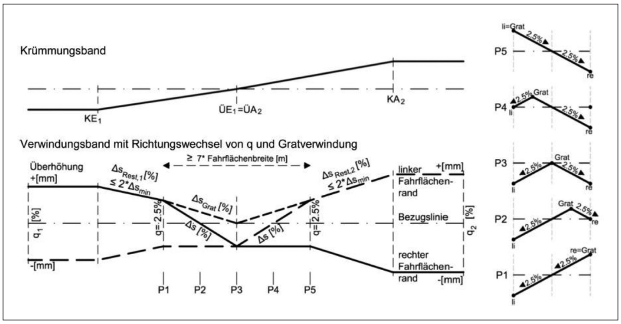

Figure 6 Inclined superelevation in Austrian guidelines [4]

4.4 German guidelines

The German guidelines for highways RAL [6] do not have inclined superelevation, but it is provided in the guidelines for motorways RAA [7]. The guidelines for motorways include [7] long-distance motorways (EKA 1 A – 130 km/h), inter-regional motorways (EKA 1 B – 120 km/h), motorway-like roads (EKA 2 – 100 km/h) and urban motorways (EKA 3 – 80 km/h). Inclined superelevation is allowed for all of them and its principles and calculation is the same as in B&H guidelines [1].

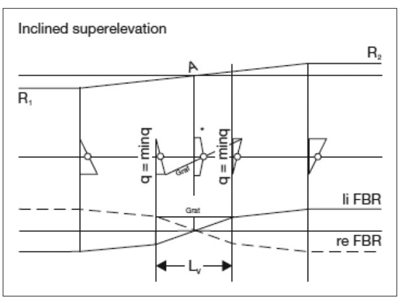

Figure 7 Inclined superelevation in German guidelines [7]

4.5 Swiss guidelines

Swiss guidelines also include inclined superelevation (Figure 8). Minimum lengths of this section are given for speeds 80, 100 and 120 km/h (Table 3).

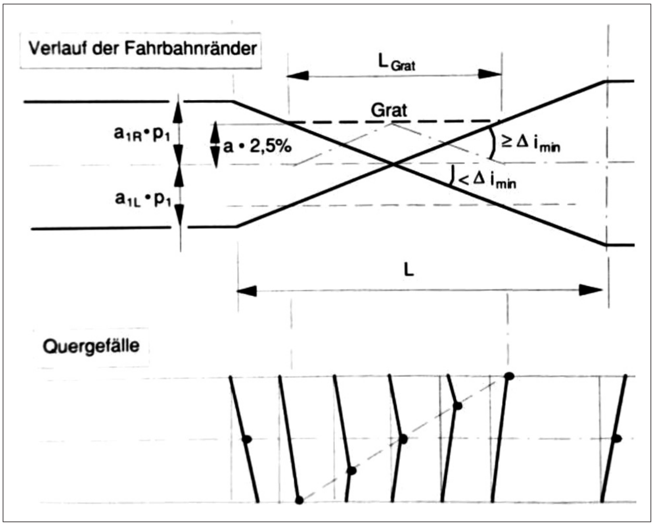

Figure 8 Inclined superelevation in Swiss guidelines [8]

Table 3 Length of inclined superelevation section in Swiss guidelines [8]

V_p [km/h]	120	100	80
L_{mn} (p = 2.5%) [m]	12 B	10 B	8 B
B = Fahrbahnbreite [m]			

4.6 TEM guidelines

TEM guidelines from 2003 propose as a solution inclined superelevation on straights (Figure 9), but these proposals are not widely accepted.

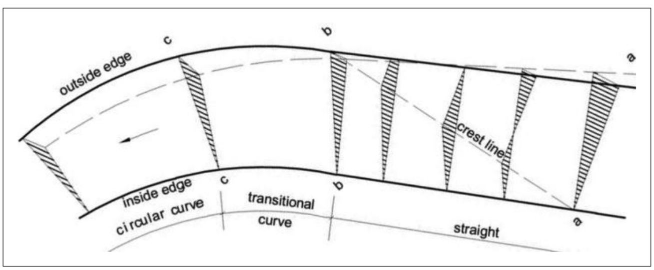

Figure 9 Inclined superelevation on straight, according to TEM standards [9]

5 Conclusion

Based on the above it can be concluded:
1) The minimum relative grade is $\Delta s_{min} = 0.1 \cdot a$, except in B&H guidelines that allow less $k_v = 0.06$ (even 0.03). The coefficient k_v less than 0.1 is not recommended and it is better to leave it out in the guidelines.
2) For high speeds the maximum relative grade Δs_{max} is close or equal to the minimum Δs_{min}.
3) It should be considered to introduce inclined superelevation in B&H and Croatian guidelines (for higher speeds). In some conditions of small longitudinal grades, the problem of drainage is probably more dominant than the potential problems of driving dynamics and aesthetics. Inclined superelevation is already present in many guidelines.

In addition, due to the significant differences between motorways and other classes of highways, it is logical to introduce separate guidelines for motorways and other highways.

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