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Superelevation Transition Assessment on Rural Roads with Reverse Consecutive Horizontal Curves

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Introduction

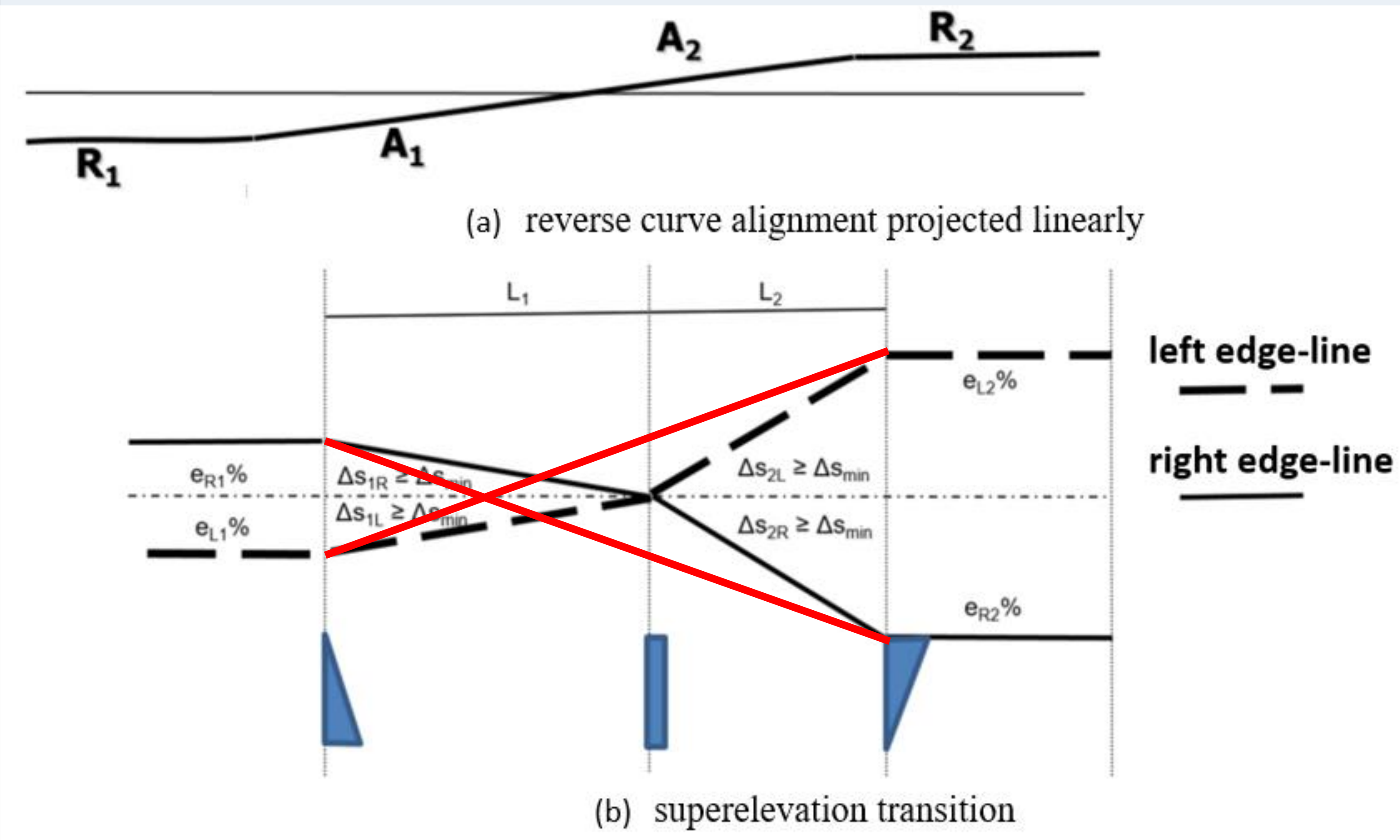
Road layouts with consecutive reverse horizontal curves consist a common practice in road design. Although the proper design of such arrangements offers many environmental and economic benefits, reverse horizontal curves impose certain safety issues to overcome.

Such an example is the **excessive centrifugal force** generated by high design speed values, or rather sharp horizontal curvature, where abrupt, uncomfortable and unsafe maneuvers, or even lateral drifting of the vehicle may result.

The effect of such unfavorable conditions can be reduced from the **superelevation (SE)** requirement, which is **critical** in terms of **counterbalancing** the **instantaneous lateral acceleration** variation caused by the centrifugal force during the curvature direction shifting.

Spiral curves provide gradual change on the centrifugal force as well as more comfortable alignment between tangents and circular curves.

During the design of consecutive curves, most European road design guidelines treat the spiral curves on both sides of the reverse curvature point as the boundaries within where the necessary SE transition takes place as well. Therefore, the point with level (horizontal) SE rate usually coincides with the point of reverse curvature.



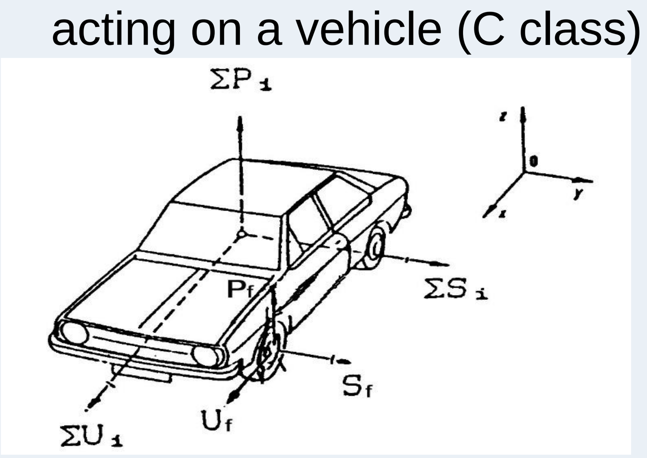
Note. (i=1,2): Ri, Ai, Li : curve i radius, spiral parameter and spiral length (m),
e_{Li}, e_{Ri}, Δs_{iL}, Δs_{iR}: curve i left and right SE rates and SE rotation rates (%),
Δsmin: minimum SE rotation rate (%).

The paper **investigates the impact of generalizing a continuous SE transition (rotation rate)** between the points where the first circular curve ends and the second circular curve begins for arrangements of reverse curves (see red lines above).

Such an alternative approach simplifies the SE rotation process as is far more construction-friendly. This assessment is performed by **quantifying** the **safety margins** in terms **of demanded friction** values for both conventional and continuous approaches, utilizing an existing vehicle dynamics model.

Methodology

The investigation is based on a **realistic** representation of the forces acting on a vehicle (C class) during tangent and curved alignments.



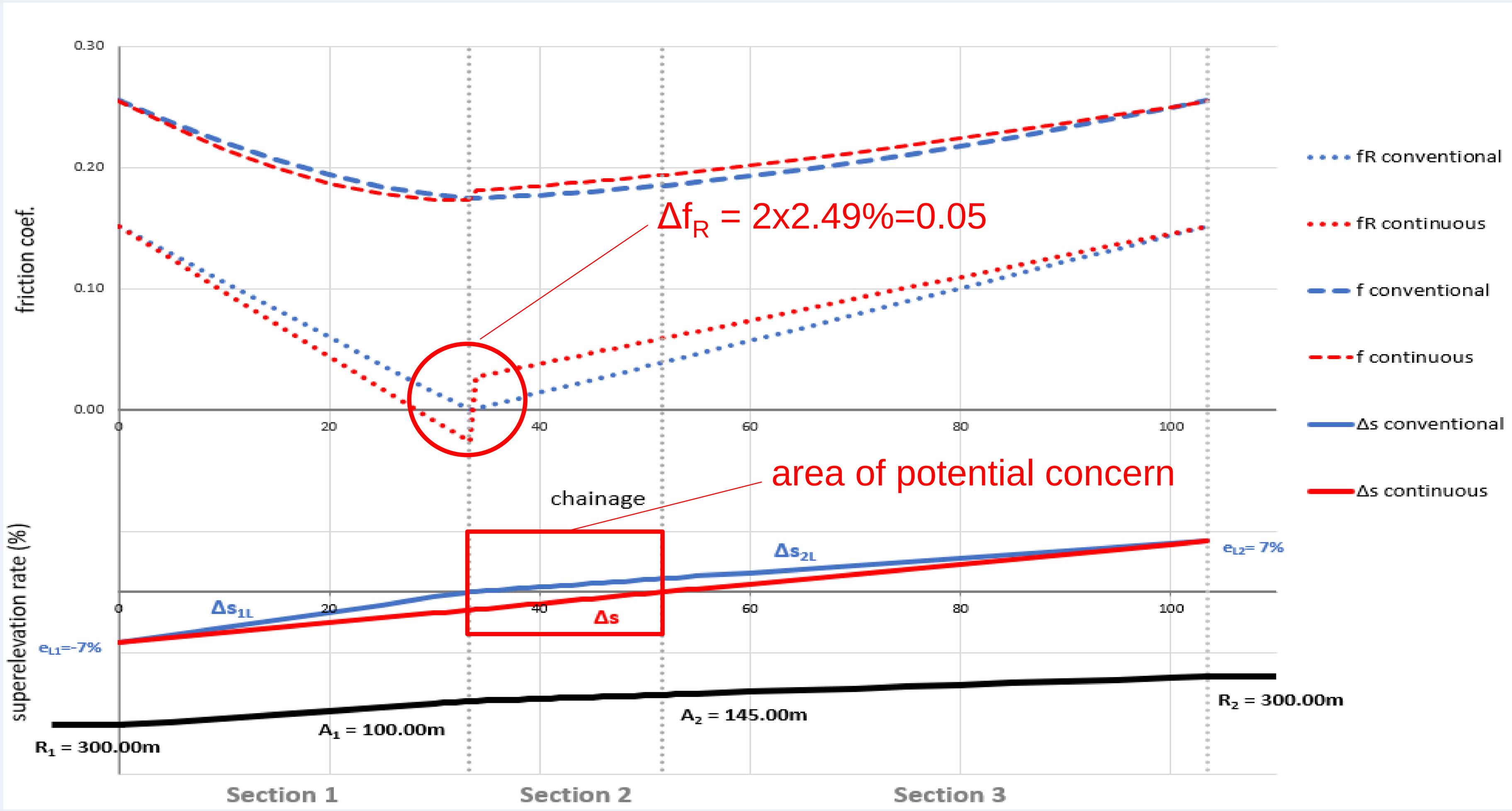
All forces and moments applied to the vehicle were analyzed into a moving three-dimensional coordinate system, coinciding at the vehicle gravity center and formed by the vehicle's longitudinal (X), lateral (Y) and vertical (Z) axis respectively.

The investigation is performed for the German rural design guidelines RAL 2012. The assessment is based on the **critical situation according to which the continuous rotation rate delivers negative SE on rather sharp circular curve**.
Therefore, **EKL 3** design class was selected
(V=90km/h, R_{min}=300m, A_{min}=R/3m, e_{max}=7.0%, Δs_{min}=0.35%, s_{max}=6.5%)

The value of **peak friction coefficients** were set to **0.30** in order to address wet pavements with poor friction performance

Analysis

The conventional (applied in current practice) SE rotation rate (CA) vs the continuous (proposed) approach (PA) for a right curve (left edge line shown) is show below. Three different sections are identified: Section 1, Section 2 and Section 3 with positive SE for both approaches, positive SE for the CA – negative for the PA, and positive SE for both approaches respectively.



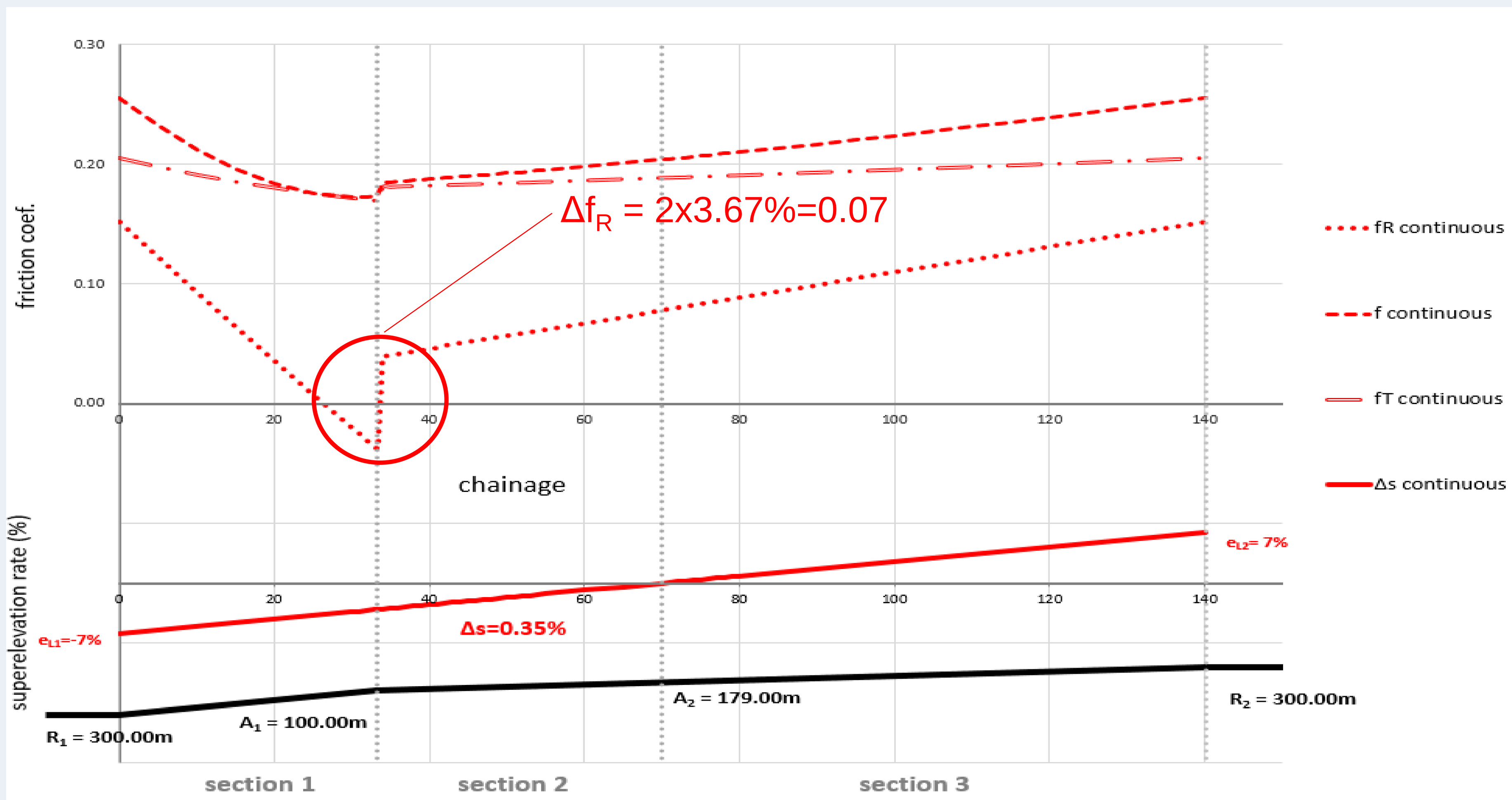
Note. f: total friction coef., f_R: lateral friction coef. of critical (inner) wheel to the curve.

$$\Delta s_i = \frac{e_2 - e_1}{A^2} Rb$$

where:
e_1: SE rate at the beginning of the spiral curve (%)
e_2: SE rate at the end of the spiral curve (%)
b: lateral distance between traffic lane's outer edge line and rotation axis (3.50m)

A_1 = 100.00m (A_{min})
Δs_{2L} = 0.35% (min) → A_2 = 145.00m

Most unfavorable case:
A_1 = 100.00m (A_{min})
Δs = 0.35% (min) → A_2 = 179.00m



Conclusions

By examining conditions under which the **negative SE rate** is **maximized at the instantaneous tangent between the reverse spirals**, and at the same time sustain the SE rotation rate to the control value of Δs_{min}=0.35%, the results, at that point, revealed that the **vehicle undergoes an immediate but rather moderate lateral friction demand variation**. This lateral friction difference, was found **0.05** and **0.07** when Δs_{min} was utilized on the conventional and continuous SE transition approach respectively.

However, before introducing the proposed approach in road design practice, there are certain issues that necessitate further research.

The present assessment needs to be validated also for speed values beyond the design speed and by investigating the acceleration - deceleration impact, especially braking (14).

In addition, since only a single passenger car was examined, further work is required to incorporate the entire vehicle fleet (SUVs, sport vehicles, heavy vehicles, etc.) as well as their related parameters.

Concluding, it should not be ignored that the human factor during the acceleration process might impose additional restrictions and, consequently, affect vehicle's safety performance.

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