XVIII SCIENTIFIC-EXPERT CONFERENCE ON RAILWAYS RAILCON '18

TRACK ALIGNMENT PARAMETERS ON MODERN RAILWAY LINES FOR MIXED TRAFFIC

Luka LAZAREVIĆ[1]
Zdenka POPOVIĆ[2]
Milica VILOTIJEVIĆ[3]
Nikola MIRKOVIĆ[4]

Abstract *– One of the most important parameters of the horizontal railway alignment is horizontal curve radius including the shape of transition curve and superelevation ramp. In case of mixed traffic railway lines, the choice of radius has to ensure a comfortable ride of passenger vehicles, safe freight transport and acceptable maintenance costs of vehicle wheels and railway infrastructure. Paper presents the experience in design of horizontal railway alignment for modern railway lines. Furthermore, paper presents theoretical analysis of cant deficiency and provides recommendations for design of track alignment according to European standard EN 13803:2017 and current practices. The main goal of this paper is to provide basis for harmonisation and advancement of national technical regulations for design of modern railway lines for mixed traffic.*

Keywords – railway infrastructure, design, horizontal curve radius, cant deficiency, cant excess.

1. INTRODUCTION

European standard EN 13803 [1] defines alignment parameters for new and reconstructed railway lines according to maximum train speed. This standard applies to nominal track gauge of 1435 mm and wider and speeds up to 360 km/h. Therefore, it covers both the speed range of conventional and high-speed railway lines.

The designer of railway line has to apply adequate values for track alignment parameters, considering the traffic safety and local conditions, as well as national technical regulations in accordance with the Infrastructure Manager preferences.

Standard EN 13803 defines six track alignment parameters, which are closely related to traffic safety: minimum radius of horizontal curve (*R*), cant (*D*), cant deficiency (*I*), uncompensated lateral acceleration (a_q), cant gradient (superelevation ramp - *D/L*) and speed (*V*). These parameters completely define railway curve alignment for the chosen design speed.

This paper presents theoretical analysis of cant deficiency and its impact to other parameters of track alignment. Furthermore, it provides recommendations for design of track alignment according to EN 13803, as well as the design experience from twelve high-speed railway line projects in Germany, France, Italy, Japan and Korea.

2. THEORETICAL ANALYSIS OF CANT DEFICIENCY

Railway vehicle is subjected to centrifugal and gravitational acceleration during curve negotiation with speed *V* (Figure 1). Difference between components of these accelerations that are parallel to the vehicle floor determine uncompensated lateral acceleration in accordance to equation (1).

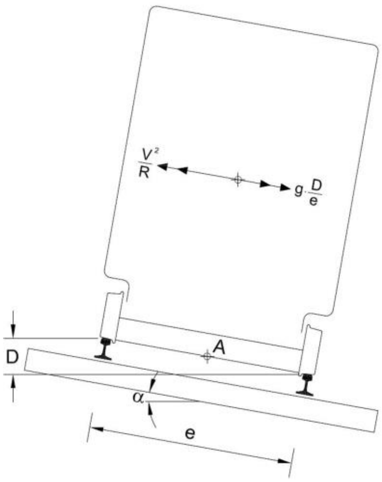

Fig. 1. Curve negotiation of railway vehicle

[1] University of Belgrade, Faculty of Civil Engineering, 11120 Belgrade, llazarevic@grf.bg.ac.rs
[2] University of Belgrade, Faculty of Civil Engineering, 11120 Belgrade, zdenka@grf.bg.ac.rs
[3] University of Belgrade, Faculty of Civil Engineering, 11120 Belgrade, mvilotijevic@grf.bg.ac.rs
[4] University of Belgrade, Faculty of Civil Engineering, 11120 Belgrade, nmirkovic@grf.bg.ac.rs

$$a_q = \frac{V^2}{R} - g \cdot \frac{D}{e} \quad (1)$$

Cant value for which a_q=0 is equilibrium cant and it is defined with equation (2).

$$D_{eq} = 11.8 \cdot \frac{V^2}{R} [mm] \ , V \rightarrow \left[\frac{km}{h}\right], R \rightarrow [m] \quad (2)$$

In the case of mixed traffic railway, changing the speed of passenger trains in equation (2) gives cant value, which is larger than equilibrium cant for freight trains. On the other hand, changing the speed of freight trains in equation (2) gives cant value, which is lower than equilibrium cant for passenger trains. Therefore, designer has to consider relation between maximum speed of passenger trains and permissible minimum speed of freight trains.

Considering equation (2) and the previous statement, it follows:

$$D + I_{lim} = 11.8 \cdot \frac{V_{max}^2}{R} \quad (3)$$

where D is designed cant, I_{lim} is the limit value of cant deficiency and V_{max} is the maximum speed of passenger trains. Furthermore, equation (4) defines minimum radius of horizontal curve for a given maximum speed:

$$R_{min} = 11.8 \cdot \frac{V_{max}^2}{D_{max} + I_{lim}} \quad (4)$$

where D_{max} is prescribed maximum cant value, which equals 160 mm according to [1]. In addition, standard EN 13803 defines exceptional cant value, which equals 180 mm. However, values larger than 160 mm can cause freight load displacement and passenger discomfort when the train stops in such track or runs with low speed [1]. Infrastructure Manager (IM) has to consider maintenance strategy and rolling stock requirements when prescribing of the maximum cant.

Furthermore, standard [1] defines 153 mm as a limit value of cant deficiency for speeds up to 300 km/h. It should be noted that in previous version of this standard limit value was 130 mm [2]. This value was increased in new version of this standard according to the experience on the European railway network. For speeds above 300 km/h, standard defines 100 mm as a limit value of cant deficiency [1].

Common practice on European railway network is to apply different cant deficiency limits to different categories of trains. For example, maximum cant deficiency in France could be 80 mm (for speeds above 300 km/h), 130 mm (for mixed traffic and conventional speed) and 160 mm (for most passenger trains). Additionally, each railway vehicle should be tested and approved in conditions covering its own range of operating cant deficiency according to the procedures defined in EN 14363 [3]. Therefore, IM has to consider train categories (speeds), track type (conventional or slab track) and local conditions (crosswind) when prescribing the maximum cant deficiency. It should be noted that high values of cant deficiency are related to the passenger discomfort.

Prescribed value of cant deficiency directly influences minimum radius of horizontal curve for a given speed, as defined by equation (4). Figure 2 shows the relation between minimum radius of horizontal curve and maximum speed for different values of cant deficiency (assuming D_{max}=150 mm as prescribed for Serbian railway network).

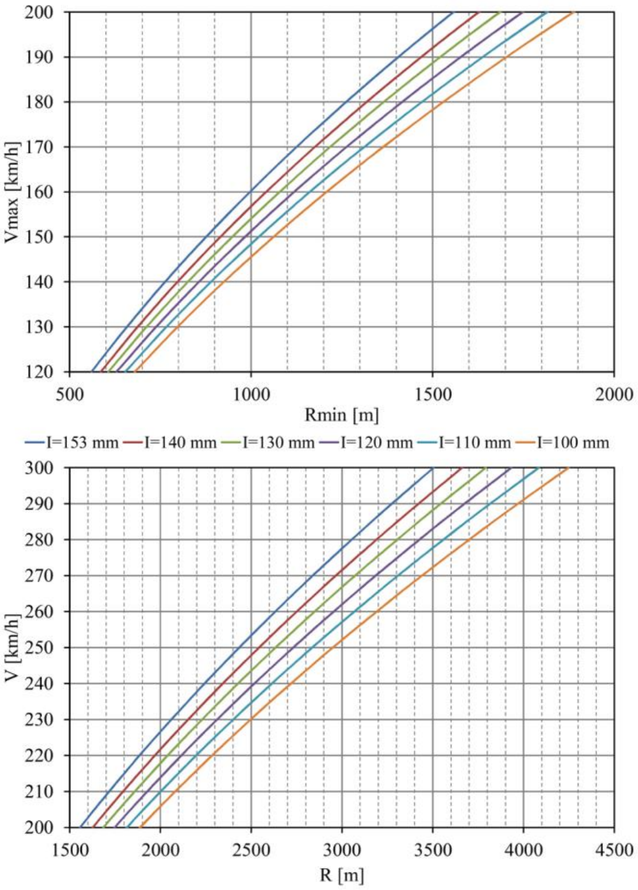

Fig. 2. Relation between minimum radius of horizontal curve and maximum speed

As it is shown in Figure 2, increasing the maximum cant deficiency leads to decrease in the minimum radius of horizontal curve. This relation is more noticeable in the speed range between 200 km/h and 300 km/h. For example, depending on the applied cant deficiency, minimum radius could vary between:

- 1000 m and 1200 m for V_{max}=160 km/h,
- 1550 m and 1900 m for V_{max}=200 km/h, and
- 3500 m and 4250 m for V_{max}=300 km/h.

3. RELATION BETWEEN CANT DEFICIENCY AND PASSENGER COMFORT

Methods for measurement and evaluation of ride comfort for passengers are defined in standard EN 12299 [4]. These methods imply determination of lateral acceleration inside the vehicle, which is experienced by the passengers. This acceleration is larger than the one defined with equation (1) and it can expresed with equation (5):

$$a_i = (1 + s_r) \cdot a_q \tag{5}$$

where a_i is uncompensated lateral acceleration inside the vehicle (parallel to the vehicle floor) and s_r is coefficient of roll flexibility that depends on the vehicle characteristics (usually between 0.2 and 0.4). Permissible value of a_i depends on the train type and could be up to 1.0 m/s^2 or more according to the current practice [5].

According to equation (1), a_q strictly depends on the V/R ratio. On the other hand, equation (4) and Figure 2 shows that the increase of cant deficiency leads to the decrease of minimum curve radius for a given speed, thus increasing V/R ratio and uncompensated lateral acceleration. Figure 3 shows the influence of cant deficiency to uncompensated lateral acceleration in minimum radius curve.

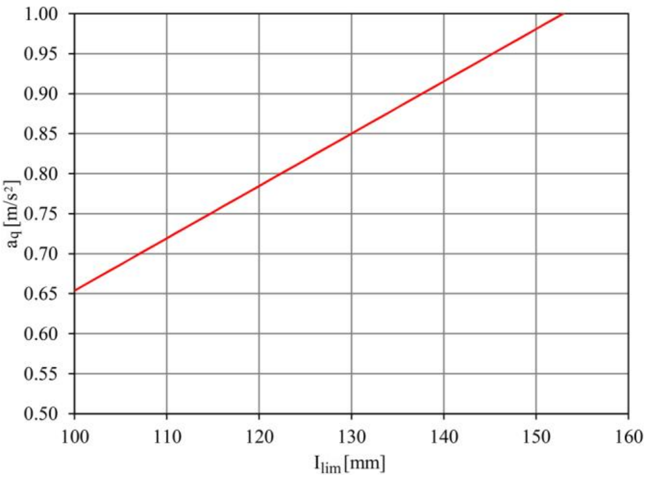

Fig. 3. Relation between cant deficiency and uncompensated lateral acceleration based on eq. (1)

Correlation between cant deficiency and uncompensated lateral acceleration (Figure 3) is independent of the speed and it could be approximated with simple linear regression. Calculated values of uncompensated lateral acceleration in minimum radius curve, which are presented in Figure 3, correspond to the limit values that are commonly applied on the European railway network.

4. RELATION BETWEEN CANT DEFICIENCY AND CANT EXCESS

Considerations presented in Chapter 2 and 3 relate to the maximum vehicle speed. In the case of mixed traffic railway lines, this speed reffers to the maximum speed of passenger trains. Therefore, cant designed according to equation (3) would be larger than equilibrium cant for freight trains. Speed of freight trains mainly depends on maximum railway gradient and vehicle characteristics. The difference between these two cant values is referred to as cant excess and is defined with equation (6):

$$D - E = 11.8 \cdot \frac{V_{min}^2}{R} \tag{6}$$

where E is the value of cant deficiency and V_{min} is the minimum operating speed of freight trains.

Large values of cant excess directly increase track maintenance costs and could lead to the vehicle derailment and overturning. Limit value of cant excess is 110 mm according to [1].

Figure 4 shows the relation between cant excess in minimum radius curve (assumed freight train speed equals 80 km/h) and design speed (maximum speed of passenger train).

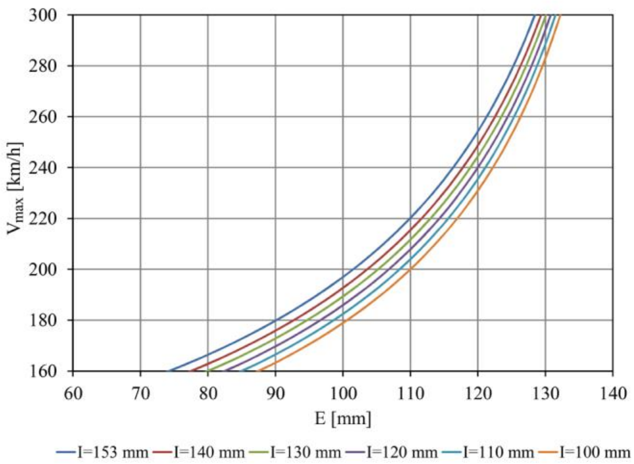

Fig. 4. Relation between cant excess in minimum radius curve and design speed

Figure 4 shows that cant excess limit value (110 mm) is exceeded for design speed above 200 km/h. Therefore, design of mixed traffic railway lines for speed between 200 km/h and 300 km/h demands increase of minimum curve radius and minimum speed, which could be performed by reducing maximum cant value and limit value of cant deficiency.

5. TRACK ALIGNMENT PARAMETERS – EXPERIENCE FROM HIGH-SPEED RAILWAY PROJECTS

According to [6], Table 1 presents applied track alignment parameters on 12 railway lines (column 1) with design speed larger than 220 km/h (columns 3-6), as well as the assessment of other parameters (columns 7-9). In addition, column 2 shows traffic type on these railway lines.

Tab. 1. Applied track alignment parameters on 12 high-speed railway lines [6]

Railway line	Traffic type	V_{max} [km/h]	D_{max} [mm]	I_{lim} [mm]	R_{min} [m]	$R_{min,calc}$ [m]	$a_{q,calc}$ [m/s^2]	E_{calc} [mm]
Manheim - Stuttgart	P+F	250	90	55	5100	5087	0.36	78
Hanover - Würzburg	P+F	250	90	55	5100	5087	0.36	78
Cologne - Frankfurt	P	300	170	150	3350	3319	0.96	-
Paris - Lyon	P (+F)	270	190	35	4000	3824	0.16	173
Paris - Le Mans	P (+F)	300	150	27	6000	6000	0.18	136
Rome - Florence	P+F	250	125	120	3000	3011	0.79	106
Tokyo - Osaka	P	220	180	60	2500	2380	0.32	-
Osaka - Okayama	P	260	180	30	4000	3799	0.13	-
Okayama - Hakata	P	260	180	30	4000	3799	0.13	-
Omiya - Niigata	P	260	155	45	4000	3989	0.29	-
Omiya - Morioka	P	260	155	45	4000	3989	0.29	-
Seoul - Busan	P	300	130	65	7000	5447	0.14	-

As it could be observed in Table 1, five projects were designed with maximum cant above 160 mm. However, these projects implied railway lines for passenger traffic only. Furthermore, railway line Cologne - Frankfurt has significanlty larger uncompensated lateral acceleration in mimimum radius curve comparing to other projects. It should be noted that IM in France considers the possibility of freight trains running on presented railway lines [6], but calculated cant excess shows that this would not be recommended.

Although three projects of mixed-traffic railway lines (grey rows in Table 1) were designed for the same speed, there is a significant difference between applied maximum cant value and limit value of cant deficiency. This shows that there are differences between decisions made by different IMs in Europe.

6. CONCLUSION

Design of mixed traffic railway lines is a very complex task from the aspect of horizontal and vertical alignment determination. Chosen parameters have to ensure safety for all vehicle types. In addition, it is necessary to ensure ride comfort for passenger trains. Meeting these requirements implies restriction of minimum and maximum speeds for passenger and freight trains.

European standard EN 13803 [1] prescribe limit values for parameters of horizontal and vertical alignment. However, Infrastructure Manager has to define limit values for above-mentioned parameters in national regulations according to the adopted railway maintenance strategy.

ACKNOWLEDGEMENT

This work was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia through the research projects "Research of technical-technological, staff and organisational capacity of Serbian railways, from the viewpoint of current and future European Union requirements" (No. 36012) and "Research challenges in implementing and operating high-speed railways in Central and East Europe: Transfer of knowledge from China and its adjustment to European rail market" (bilateral project between Serbia and China).

REFERENCES

[1] CEN, *EN 13803 Railway applications - Track - Track alignment design parameters - Track gauges 1435 mm and wider*, 2017.

[2] CEN, *EN 13803-1 Railway applications - Track - Track alignment design parameters - Track gauges 1435 mm and wider - Part 1: Plain line, 2011.*

[3] CEN, *EN 14363 Railway applications - Testing and Simulation for the acceptance of running characteristics of railway vehicles - Running Behaviour and stationary tests*, 2017.

[4] CEN, *EN 12299 Railway applications - Ride comfort for passengers - Measurement and evaluation*, 2010.

[5] Lazarević, L., *Rampa za nadvišenje kao prostorni element trase železničke pruge (Superelevation ramp as the spatial element of railway alignment), University of Belgrade, Serbia, 2010. (in Serbian)*

[6] Hartmann, J., Lay, E., Beck, A., *Hoch geschwindigkeits strecke Köln - Rhein/Main (High-speed railway line Köln - Rhein/Main)*, ETR, Vol. 55, 2006, pp. 372-380. (in German)