



REDUCTION OF EXTERNAL RAIL WEARING ON ROAD CURVES

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Abstract. Railway line curves restrict train speed. Besides, there is a high side wearing intensity in the external rail head on the curves. The main functions of cant are discussed in the article. Results of experimental research which was carried out in order to estimate the influence of cant and gauge increase on the curves of rail head side wearing intensity, are presented. Improved cant calculation methodology, which assures rail head side wearing intensity reduction and safe railway traffic, is suggested.

Keywords: cant, rail head side wearing intensity, undamped acceleration, curve.

1. Introduction

Railway is safe, convenient and ecological type of transportation. About 43 % of the loads carried across our country are carried by Lithuanian railways (in 2001 about 36 %) [1].

The main property of railway system is infrastructural objects and rolling-stocks. To keep any kind of property huge expenses is needed and renovation investments are necessary [2]. The present Lithuanian railways transport sector as well as this sector in many other Eastern and Middle European countries is rather behind modern Western and Northern European interrelated railway transport systems, in technical, economical, technological and organisational points of view [3]. For modernisation of Lithuanian railway lines infrastructure it is committed 70–80 % of the whole investments intended for Lithuanian railways. According to Lithuanian railways infrastructure renovation and development programme it is intended to invest about 400 mln EURO for modernisation of railways [4]. The purpose of the modernisation is to increase freight trains speed up to 100 km/h and passenger trains speed up to 160 km/h [5].

Railway lines are made of straight sections and curves. Train driving on the curves essentially differs from that one in straight sections. At present in some sections of main Lithuanian railway lines it is possible to reach only 50 km/h speed [6]. On the curves railway gauge is widened (when curve radius is less than 350 m), cants are mounted. In various countries, curves make between 20 and 30 % of the overall railway length (31,1 % in Lithuania), however, increased forces acting on train on the curves results in an intensive wear of upper rail road structure elements and rolling-stock

wheels rims. Concerning worn rolling-stock wheels and rails, while driving on the curve, passengers feel uncomfortable, vibration and noise. Also noise harms people living nearby railway [7]. After railroad construction or railroad and train maintenance conditions radical change, the problem considerably increased, although purpose to decrease external rail head side wearing intensity on the curves exists as long as railways [8, 9].

Changing the worn rails increases railway maintenance expenses. Therefore it is important to estimate factors influencing external rail wearing on the curves as well as to forecast wearing intensity when evaluating these factors.

2. Analysis of intensive rail wearing problem

External rail wearing is influenced by uncontrolled (railway line plan and profile), partially controlled (train weight, axial loads) and controlled (train speed, rail and wheel steel toughness, lubrication of wheel and rail, cant, gauge) factors. Uncontrolled factors can be changed only during the reconstruction of the railway line, changes in partially controlled factors related to reorganisation of maintenance work [10].

The influence of controlled factors on rail wearing is analysed mostly. After analysis of other researchers it was reached that the focus is now on improvement of the quality of rail and wheel steel, to find the optimal wheel flange/rail head profile which provides minimal wear, as well as development of more advanced rail and wheel lubrication substances [7, 8, 11–13]. The analysis showed the insufficient efforts in the past to explore the possibility of reducing the intensity of rail head side

wearing on curves by improving gauge standards regulating the widening of gauge and methods of calculating cant.

The aim of the article is to find how to diminish the intensity of external rail head wearing by improving the calculation of the external rail cant. For that purpose the analysis of calculation methods of rail cant has been performed and the shortages examined. The results of experimental investigation have been presented in order to define the influence of external rail cant and railway gauge on wearing of rails. These tasks were investigated using analytical and statistical research methods.

Forces acting on train on curves are presented in Fig 1. For decreasing centrifugal forces influencing rolling-stock and external rail, for diminishing rails and rolling-stock wheels wear and to avoid unpleasant feelings while driving on curves (with radius of 4000 m and less) cants are mounted [14].

Undamped acceleration α is different between centrifugal force F and centripetal force F_h . The less undamped acceleration acts on curve, the less is rail wearing [8, 15].

Undamped acceleration α (m/s^2), at any point of curve is calculated according to the formula:

$$\alpha = \frac{v_{\max}^2}{3,6^2 \cdot R} - 0,00613 \cdot h_p, \quad (1)$$

where v_{\max}^2 – maximal train speed on the curve (km/h); R – curve radius (m); h_p – cant value (mm).

In Lithuania permissible undamped acceleration norm for passenger trains is $\alpha_{kel} = 0,7 \text{ m/s}^2$, for freight trains $\alpha_{krov} = \pm 0,3 \text{ m/s}^2$ (negative undamped acceleration appears when freight train speed is small).

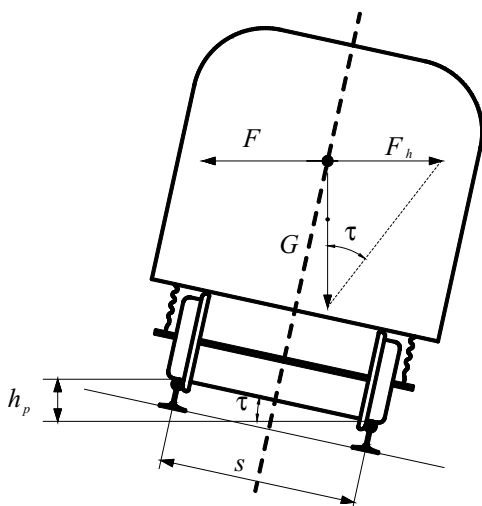


Fig 1. Scheme of forces acting on the curve: F – centrifugal force; F_h – centripetal force; s – distance between rail axes; h_p – difference of external and internal rail heads height (cant); G – ωειγητ οφ τηε ρολλινγη-στοχη; | ∈ δεχλιναπιον ανγηε οφ αξεσ ατ τηε ποιιντ οφ ηοριζον

The main problem when estimating the cant size is train speed. More perfect methods are needed for calculating more precisely. As the main difficulties appear because of mixed traffic, it is necessary to find a way how to properly evaluate difference of passenger and freight train speed. When calculating the cant, it is necessary to evaluate not only maximal passenger train speed but also the actual freight train speed.

In many countries the external rail cant is defined by the undamped acceleration value. Such a way of calculation is possible only when the technical state of the rolling-stock is good and the load transportation makes only a small part of carriage. By applying this calculation method there is no need to define the average train speed (the definition with a certain reliability is a complicated task).

After situation analysis carried out in the same sphere, five groups of measures that would reduce rail side wear in the aspect of factors under research are set:

1. To look for possibilities to separate freight and passenger train traffic lines. This measure is the most expensive and at present there are no possibilities to establish it in Lithuania.
2. To increase freight trains speed renovating old locomotives. In Lithuania locomotive park renovation and modernisation programme is prepared. It plans to modernise 29 2M62 type locomotives and to purchase 34 new modern locomotives, satisfying EU requirements. Dead line of the programme is the year 2008 and value of the project is over 100 million EURO. In the strategy of the freight wagonloads renovation and purchasing, it is planned to renovate half of the company's freight wagonload park (about 4500 wagonloads). Deadline of the program is the year 2015 and value of the project is approximately 85 million EURO [1].
3. To change the valid norm of the undamped acceleration, reducing it from $0,7 \text{ m/s}^2$ to $0,6 \text{ m/s}^2$ for passenger trains. For freight trains the present valid undamped acceleration norm should be left ($\pm 0,3 \text{ m/s}^2$). This proposal is suggested taking into consideration reduction possibilities of the rail head side wearing intensity and taking into account experience of other countries. Permissible undamped acceleration norms for passenger trains in some other countries are presented in Table 1 [16]. The permissible undamped acceleration norm for passenger trains in most countries is less than in Lithuania.
4. To change cant calculation method on the curves. Mean train speed and passenger train permissible undamped acceleration is not enough for calculations. It is necessary to check whether actual freight trains speed satisfies passenger trains maximum permissible speed, in order permissible undamped acceleration norm for freight trains was not exceeded.

Table 1. Maximum permissible undamped acceleration for passenger trains in some countries

Country	α_{kelb} , m/s ²
Austria	0,65
Belgium	0,6
France	0,85–0,98
Spain	0,65
Japan	0,8
Germany	0,65
Poland	0,6
Russia, Lithuania	0,7
England	0,6
Czech Republic	0,6
USA	0,5
Italy	0,6

5. To widen the railway gauge S in the curves with radius $R \leq 650$ m in the following order:
 $S_{R \leq 350m} = 1535$ mm; $S_{350m < R \leq 400m} = 1530$ mm;
 $S_{400m < R \leq 650m} = 1524$ mm [10].

In the countries where passenger trains traffic lines are separate from that of freight trains (Germany, Japan, France, etc) rail wearing decrease problems are solved differently than in the countries such as Lithuania and Russia, where train traffic is mixed. Picquand researched possibilities how to make cant deficiency less restrictive through the use of vehicles designed to compensate the cant deficiency (tilting trains) and by raising maximum cant on curves and thereby curve negotiation speeds under certain specific conditions [17]. Weakness of the research is that the main purpose of the research is to increase train speed not evaluating wearing of rails and wheels.

In Russia research to define the cant influence on rail wearing was carried out by Andreev A. I., Komarov K. L., Karpuschenko N. I., Kamenski V. B. Andreev, A. I., Komarov, K. L. and Karpuschenko, N. I. The research shows that cant increasing decreases rail wearing. The authors suggest to increase the calculated external rail cant by 20 % on curves with a radius less than 400 m [18]. Kamenski recommends to calculate external rail cant by statistical and analytical methods, ie to use average square speed in the first case and to set speeds before starting calculations in the second case [16]. Pevzner and others suggest to calculate the cant with permissible undamped acceleration α from 0 up to 0,1 m/s² on curves with radius less than 600 m [19].

We suggest to improve the cant calculation methodology in order to decrease rail wearing intensity in the following ways: to use decreasing permissible undamped acceleration for passenger trains up to 0,6 m/s²; to use correct formula for calculating cant on the curves with radius less than 350 m and to check whether the freight trains actual speed satisfies the maximum permissible passenger train speed.

3. Experimental research of cant and gauge influence on rail head side wear intensity

The aim of the experimental research was to identify the influence of cant and gauge width on external rail head side wearing intensity.

During experiments carried out in June 2001 – September 2002 the task was to estimate cant and gauge influence on rail head side wearing intensity. The research was carried out on 19 curves of Lithuanian railway lines. The upper structure of the railway on the curves under research is as follows: rails UIC60 (tempered), reinforced concrete sleepers, crushed stone ballast. The measurements were done in the length of the orbicular curve near every tenth rail axis. Every curve contained from 25 to 35 measurement points (taking into account curve radius) [10]. In every fixed curve point cant, gauge and external rail head side wear was measured and rail head side wear intensity ω'_s was calculated according to the formula:

$$\omega'_s = \frac{\Delta\omega}{I} \cdot 10, \text{ mm/10 mln t}, \quad (2)$$

where $\Delta\omega$ – change of rail head side wear during the research (mm); I – amount of the carried loads during the research, mln T.

Regression analysis for experimental research was done, describing the relationship between external rail side wearing intensity and cant value or gauge (confidence level – 95 %).

Dependence of rail head side wearing intensity on cant are shown in Fig 2 and Table 2.

It is seen in the dependences that external rail head side wearing intensity decreases, when the cant is increased.

During the experimental research cant on the curves was measured. During analysis of the obtained results, undamped acceleration was calculated according to formula (1). Maximal permissible passenger trains speed is used in calculations [20], ie undamped acceleration, which appears when passenger train speed is maximal permissible.

Influence of undamped acceleration on external rail head side wearing intensity is presented in Fig 3 and Table 2.

When passenger train speed on the curve decreases, undamped acceleration decreases as well. It is necessary to calculate undamped acceleration for the actual freight trains speed on the curve: however such speed is not recorded and therefore additional research is needed.

The research results of influence of gauge on rail head side wear are presented in Fig 4 and Table 2.

According to the research results it is recommended to widen gauge on the curve in the following order: to widen the gauge up to 1524 mm on the curves with radius $400\text{ m} < R \leq 650$ m; to widen the gauge up to 1530 mm (at present it is 1520 mm) on the curves with

Table 2. The main characteristics of the experimental research

Fitted model number	Curve radius, m	Equation of the fitted model	Correlation coefficient	Note
The experimental research is shown in Fig 2				
1	650	$\omega_s' = e^{(0,507175 - 0,00822873 \cdot h_p)}$	0,811	tempered UIC60 rails
2	700	$\omega_s' = e^{(0,549867 - 0,0119512 \cdot h_p)}$	0,794	tempered UIC60 rails
3	900	$\omega_s' = e^{(0,375773 - 0,00942283 \cdot h_p)}$	0,853	tempered UIC60 rails Section Vilnius – Paneriai
4	900	$\omega_s' = \frac{1}{(0,506299 + 0,0259557 \cdot h_p)}$	0,88	tempered UIC60 rails Section Vilnius – N.Vilnia
5	1500	$\omega_s' = \frac{1}{(0,421897 + 0,0464218 \cdot h_p)}$	0,917	tempered UIC60 rails
The experimental research is shown in Fig 3				
1	650	$\omega_s' = \frac{1}{\left(0,148516 + \frac{0,776012}{\alpha}\right)}$	0,851	tempered UIC60 rails
2	700	$\omega_s' = 1,22546 \cdot \alpha - 0,0773631$	0,821	tempered UIC60 rails
3	900	$\omega_s' = \frac{1}{\left(0,271802 + \frac{0,967689}{\alpha}\right)}$	0,864	tempered UIC60 rails Section Vilnius – Paneriai
4	900	$\omega_s' = \frac{1}{(4,20549 - 4,25155 \cdot \alpha)}$	0,881	tempered UIC60 rails Section Vilnius – N. Vilnia
5	1500	$\omega_s' = \frac{1}{\left(0,781967 + \frac{0,86406}{\alpha}\right)}$	0,917	tempered UIC60 rails
The experimental research is shown in Fig 4				
1	$R \leq 350$ m	$\omega_s' = 0,0169818 \cdot S^2 - 52,21 \cdot S + 40131,5$		R65 class rail
2	$350 < R \leq 400$ m	$\omega_s' = 18205,4 - 23,7689 \cdot S + 0,00775879 \cdot S^2$		UIC60 class rail
3	$400 < R \leq 650$ m	$\omega_s' = -62,8125 + \frac{96808,4}{S}$	0,862	UIC 60 class rail

radius $350 \text{ m} < R \leq 400 \text{ m}$. When gauge width is 1520 mm, rail side wearing intensity increases twice. On the curves with radius less than 350 m, gauge increment up to 1535 mm assures the minimal rail head side wearing intensity.

A comparison of the research results with other investigations shows that the results obtained are similar, the dependences and conclusions are similar, though actual values are different conditions under which the research took place. When the undamped acceleration is diminished up to $0,55 \text{ m/s}^2$, the intensity of external rail side wearing decreases by 3 times [18], in our research by 2,2 times (Fig 5). In both cases the curve with the

radius of 650 m was investigated, only in our experiments the rails were hardened rail of UIC 60 type (other researchers used R65 type rails).

4. Improvement of cant calculation method for decreasing rail wearing

It is estimated that the increase of external rail cant and gauge widening decreases rail wearing intensity on curves. Therefore it is suggested to widen the gauge on the curves with radius less than 650 m [10] and to apply a smaller permissible undamped acceleration norm for passenger train ($0,6 \text{ m/s}^2$).

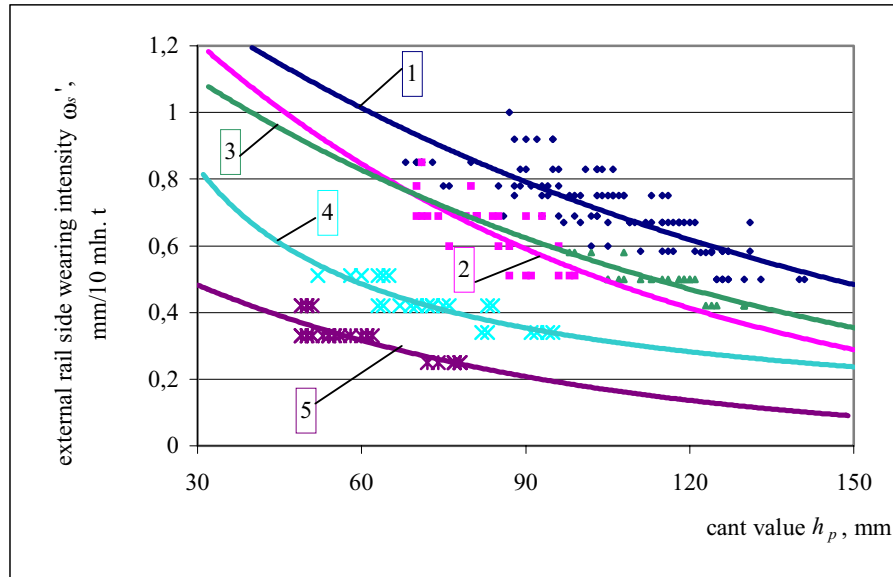


Fig 2. Dependence of rail head side wearing intensity on cant

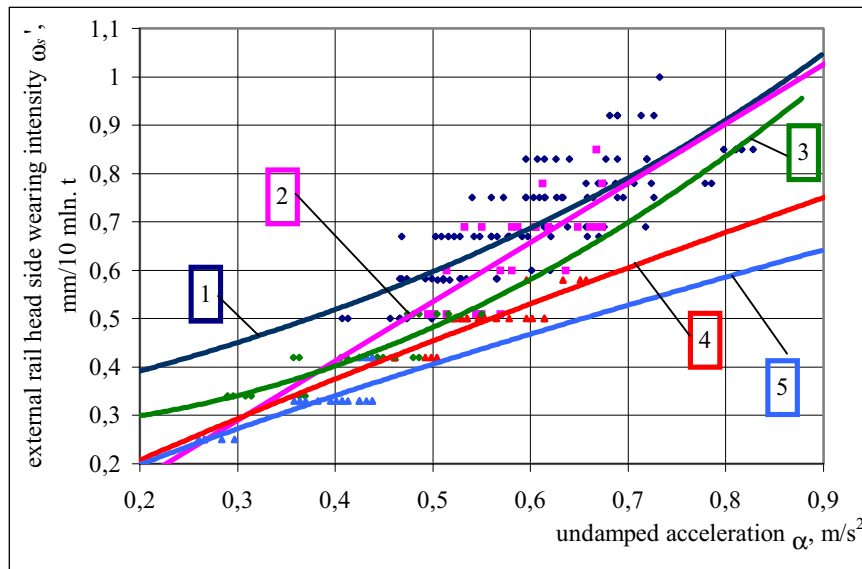


Fig 3. Dependence of rail head side wearing intensity on undamped acceleration

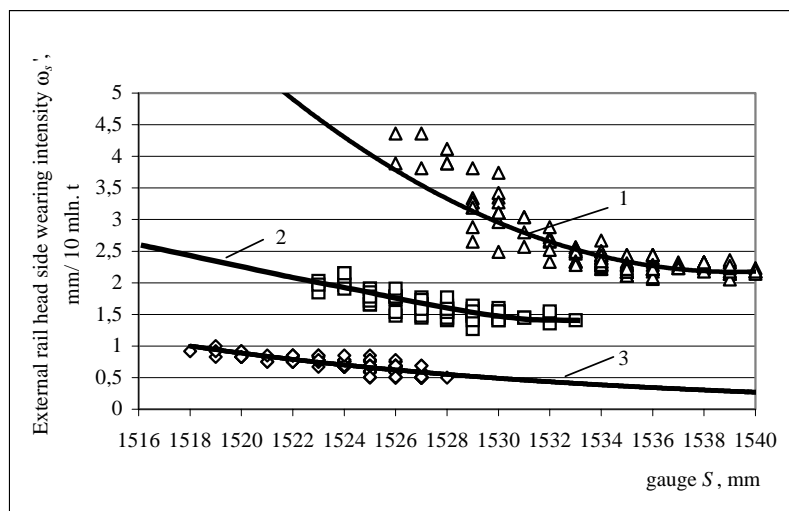


Fig 4. Dependence of rail head side wearing intensity on gauge

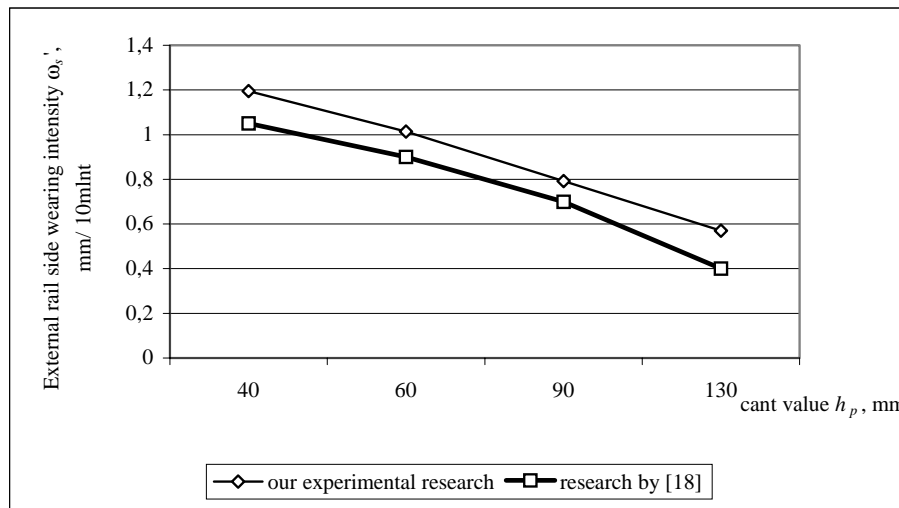


Fig 5. Dependence of rail head side wearing intensity on cant

At present the cants h_p , m, are determined by formula [15]:

$$h_p = \frac{s \cdot v_{mean}^2}{g \cdot R}, \tag{3}$$

where: R – curve radius, m; v_{mean} – actual mean velocity of freight and passenger trains passing the curve (per year), m/s; g – free fall acceleration, m/s²; s – distance between rail axes (when gauge $S=1520$ mm, s is assumed to be 1600 mm).

In order to express the cant h_p by millimetres, speed v_{mean} by km/h and railway curve radius R by meters, the expression (3) is rewritten using the transfer coefficients:

$$h_p = 12,5 \frac{v_{mean}^2}{R}. \tag{4}$$

Size of the platform is checked according to the formula [14]:

$$h_{p\min} = 12,5 \frac{v_{\max}^2}{R} - 163 \cdot \alpha_{kel} = 12,5 \frac{v_{\max}^2}{R} - 115, \tag{5}$$

where: $h_{p\min}$ – minimal calculated cant, mm; v_{\max} – maximal passenger trains speed on the curve, km/h; 115 – maximal permissible platform size in millimetres, when undamped acceleration set norm is not exceeded for passenger trains in Lithuania (0,7 m/s²); R – curve radius, m.

When permissible undamped acceleration is reduced to 0,6 m/s², the formula (5) is rewritten as:

$$h_{p\min} = 12,5 \frac{v_{\max}^2}{R} - 98. \tag{6}$$

The cant estimation methodology should be comple-

mented with the formula, checking if actual freight trains speed satisfies the maximum passenger trains speed [16]:

$$v_{krov}(\alpha=-0,3m/s^2) \geq v_{krov} \geq v_{krov}(\alpha=0,3m/s^2) \tag{7}$$

The left and the right sides of the inequality are calculated according to the formula (6). Formula, checking whether the actual freight trains speed satisfies maximum passenger trains speed, is obtained:

$$\sqrt{v_{\max\,kel}^2 - 3,9 \cdot R} \geq v_{krov} \geq \sqrt{v_{\max\,kel}^2 - 11,7 \cdot R}. \tag{8}$$

The larger obtained value of the cant is taken according formulas (4) and (6), but not more than 150 mm and it is checked according the formula (8).

In the expression (3) for the curves with radius less than 350 m ($S = 1535$ mm), we suggest using $s = 1635$ mm instead of $s = 1600$ mm. Therefore for the curves with radius less than 350 m, the cant could be calculated according to the formula:

$$h_p = 12,7 \frac{v_{mean}^2}{R}. \tag{9}$$

Then formula (8) is rewritten as:

$$\sqrt{1,01 \cdot v_{\max\,krov}^2 - 3,9 \cdot R} \geq v_{krov} \geq \sqrt{1,01 \cdot v_{\max\,kel}^2 - 11,7 \cdot R}. \tag{10}$$

Calculation methods are presented in Table 3.

New methods are applied when calculating the cant on the Lithuanian railway lines curves under research. The results are presented in Fig 6. When cant is calculated according to the suggested improved methodology, the obtained cant value of the most of curves is bigger than the one according the methods used at present.

Table 3. Comparison of valid and new methods

No	Curve radius R, m	Cant calculation formula
Valid methods		
1	<4000	$h_p = 12,5 \frac{v_{mean}^2}{R}$,
2		$h_{p\ min} = 12,5 \frac{v_{max}^2}{R} - 115$,
Suggested methods		
1	<350	$h_p = 12,7 \frac{v_{mean}^2}{R}$,
2		$h_{p\ min} = 12,5 \frac{v_{max}^2}{R} - 98$,
3		$\sqrt{1,01 \cdot v_{max\ krov}^2 - 3,9 \cdot R} \geq v_{krov} \geq \sqrt{1,01 \cdot v_{max\ kel}^2 - 11,7 \cdot R}$
1	350-4000	$h_p = 12,5 \frac{v_{mean}^2}{R}$,
2		$h_{p\ min} = 12,5 \frac{v_{max}^2}{R} - 98$,
3		$\sqrt{v_{max\ kel}^2 - 3,9 \cdot R} \geq v_{krov} \geq \sqrt{v_{max\ kel}^2 - 11,7 \cdot R}$,

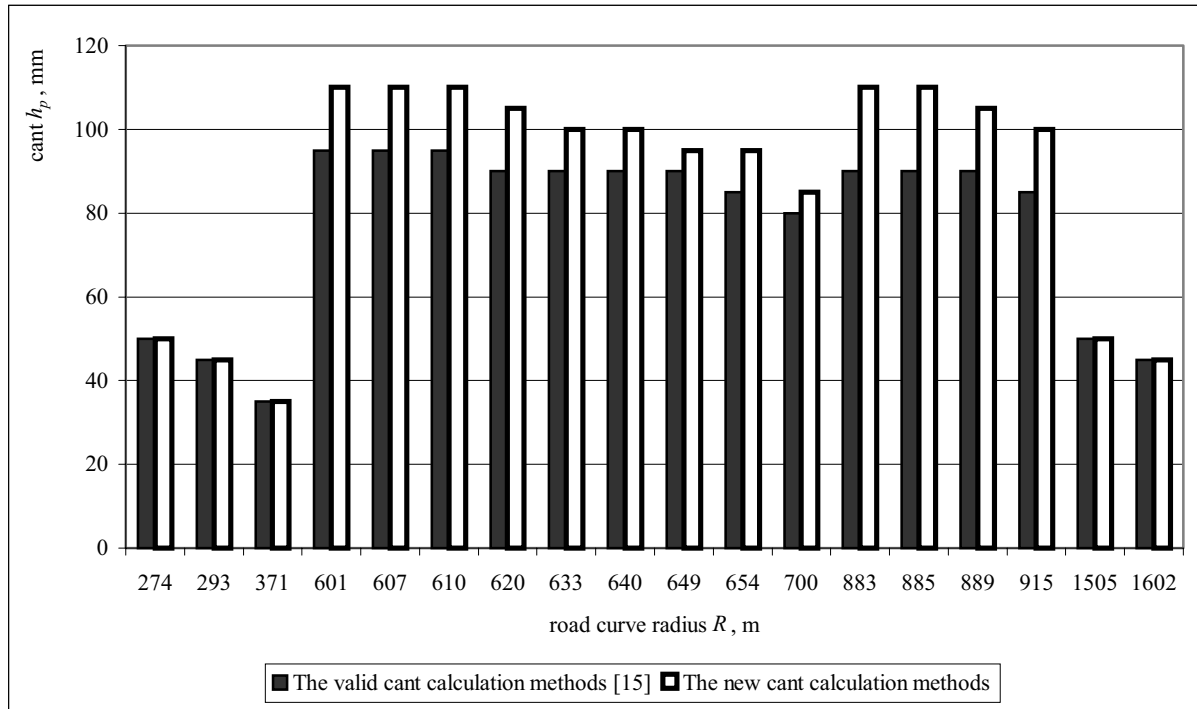


Fig 6. Cant h_p on the curves under research

5. Conclusions

1. Changing the worn rails increases railway maintenance expenses. Therefore it is necessary to investigate factors influencing external rail wearing on the curves. In the article two factors influencing rail wear are analysed – the cant and the gauge on the curves.

2. The results of the experimental research carried out on 19 Lithuanian railway lines curves have shown that increase of cant (as well as decrease of undamped acceleration) and widening of the gauge on the curves with radius less than 650 m, decreases external rail head side wearing intensity.

3. Reduction of the permissible undamped acceleration to $0,6 \text{ m/s}^2$ for passenger trains would produce a bigger cant than the current cant calculated according to the existing methods.

4. In order to decrease external rail head side wearing intensity on the curves, suggestions to improve cant calculation methodology are presented. In the calculations it is suggested to use corrected formula for the curves with radius less than 350 m, to decrease the permissible undamped acceleration norm for passenger trains and to check whether the freight trains actual speed satisfies the maximum permissible passenger train speed.

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