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Investigation of the Operation of the Railway Track with Reinforced Concrete Sleepers in Curved Sections with Radius R ≤ 350 m

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Abstract

The article presents the results of the research on polygon extension for laying reinforced concrete sleepers under difficult conditions (R≤350 m, mountainous terrain) with ensuring safety traffic and reliable operation of the railway track. Changes in the geometry of the track in the plane with wooden sleepers and Д0 fastener as well as reinforced concrete sleepers with СКД65-Б fastener in the curve with the radius of 350 m were investigated. The results of the research allowed to obtain:

- method and algorithm for determining the tapping section of the track gauge extension on reinforced concrete sleepers in curves with radius R ≤ 350 m;
- comparative assessment of the track gauge change with the use of Д0 fastener (wooden sleepers) and СКД65-Б fastener (reinforced concrete sleepers) in curves with a radius R ≤ 350 m;
- factors impact on the track gauge extension under difficult operating conditions;
- empirical dependence of the process of the track gauge width change and the frequency of its adjustment in the cases of СКД65-Б fastener (reinforced concrete sleepers) and Д0 fastener (wooden sleepers) use in curves with radius R ≤ 350 m;
- conclusions on the probability and feasibility of concrete sleepers use under mountainous terrain conditions, including difficult operating conditions (R ≤ 350 m).

KEY WORDS: *railway track, rail fastener, rail track width, rail track hold in the plane*

1. Introduction

The train speed increase and axial loading require the increase of the railway track strength and stability. The possibility of further implementation of this approach depends significantly on the reliable operation of the elements of the railway track. It should be noted that, from the point of view of reliability, the most unpredictable and difficult for operation and maintenance is the railway track located in the mountains, including difficult operating conditions (R≤350 m). One of the important problems in maintaining such curves is the considerable length of track sections with wooden sleepers, which depends on a large percentage of curves with a radius of 350 ÷ 200 m. Such railway track is less reliable in curved sections than the railway track with reinforced concrete sleepers.

At the initial stages of operation, the track on wooden sleepers has small rigidity, which provides spatial elasticity of the elements of the upper track structure (hereinafter UTS) with simultaneous taking over both vertical and horizontal dynamic forces from the rolling stock. Despite its advantages, the railway track with wooden sleepers has a number of disadvantages that make it economically unprofitable for the use. In case of the increased train load on the track 75…130 kN in the horizontal plane, which is typical for curved sections of the track with R ≤ 350 m, frequent disorders of the track geometry in the plane take place [1-2]. In the track with wooden sleepers the main work is track levelling in the plane, as disorders shorten the life of wooden sleepers almost twice [3-4]. Due to mechanical damage, wooden sleepers in curves do not have time to rot and are removed from the track after about 5-7 years, which is 5 times less than the service life of concrete sleepers [3, 5-12]. Even today, wooden sleepers are in short supply, very expensive, and according to the scientists' research of Dnipro National University of Railway Transport (hereinafter referred to as DNURT), the cost for track maintenance with wooden sleepers increases by 25-31.5% [13].

Based on the above problem of railway track operation on wooden sleepers in curved sections with radius R ≤ 350 m, it is necessary to:

– to develop recommendations on the use of reinforced concrete sleepers in curved sections R ≤ 350 m with reliable retention of track gauge geometry in the plane;

– to develop the method of track geometry retention on reinforced concrete sleepers in the plane for curves with radii less than 350 m. The results of the researches will allow to substantiate more detailly the work of the railway track in the mountains, including difficult operating conditions.

2. Methodology and Algorithm for Section Determining of the Track Extension Tapping on Reinforced Concrete Sleepers in Curves with Radius R ≤ 350 m

Before assembling the rail-sleeper grid (hereinafter RSG), measurements are made to establish a clear position for the beginning and the end of the transition curve [14]. The next step is to determine where the track extends from the track width in the straight line (S_S) to the track width in the circular curve (S_{CK}). The scheme of tapping the track gauge extension within the transition curve by means of fastening is shown in Fig. 1.

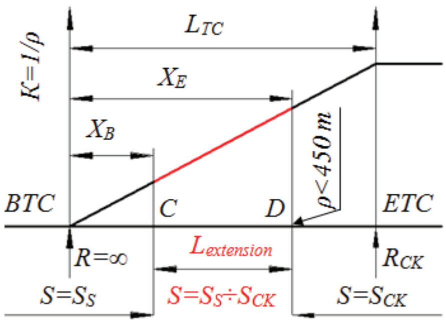

Fig. 1 The scheme of the position of track extension tapping in the transition curve

Symbols: BTC, ETC – respectively, the beginning and the end of the transition curve; X_B, X_E - respectively, the beginning and the end of the section of track extension tapping; S_S - track width in a straight section; S_{CK} - track width in a circular curve; L_{TC}, $L_{extension}$ - respectively, the length of the transition curve and the section of track extension tapping.

The end of the extension tapping is determined by the formula:

$$X_E = \frac{R_{CK} \cdot L_{TC}}{\rho}, \tag{1}$$

here R_{CK} - radius of a circular curve; L_{TC} - length of a transition curve; ρ - radius from which the track width begins in a circular curve.

The beginning of the extension tapping is determined by the formula:

$$X_B = X_E - k \cdot b, \tag{2}$$

here b - is the distance between adjacent sleepers, m, which depends on the number of sleepers per 1 km of the railway track; k - the number of sleepers in the section of track extension tapping.

Extension tapping is made in the section where k sleeper is laid. Thus, up to point *C*, which is situated at the distance X_B from the beginning of the transition curve, the width standard of the track is equal to the track width for straight sections ($S = S_S$). In section CD the smooth track widening is performed from the track width on the straight line to track width on the circular curve ($S = S_S \div S_{CK}$). From point *D* onwards on the transition and circular curves, the track gauge is S_{CK} (the standard gauge width for a particular curve). This technique is versatile because it can be used for different track gauge widths in both straight and curved sections.

3. Ground Tests of Track Gauge Width Changes on Wooden and Reinforced Concrete Sleepers in Curves with Radius of 350 m

The conducted researches were based on the comparative estimation of dynamics influence of track gauge change on wooden sleepers with Д0 fastening and reinforced concrete sleepers with СКД65-Б fastening in curved sections of the track with radius 350 m.

At present, with the appearance of СКД65-Б fastener [15-16], it is possible to use reinforced concrete sleepers in curved sections of the track of any radius without changing the construction of the reinforced concrete sleepers. The use of reinforced concrete sleepers and СКД65-Б fastener (Figs. 2-3) allows to avoid many problems arising in the railway track on wooden sleepers. СКД65-Б fastener can shape the track geometry in a curve section, namely, gradually extend the track from 0 mm to 14 mm, and narrow from 0 mm to 28 mm. This allows adjusting the track width within 1 mm when the rails are worn during operation. The principle of СКД65-Б fastener operation is based on the technique of smooth tapping the track gauge extension within the transition curve applying adjusting cards (see Fig. 1).

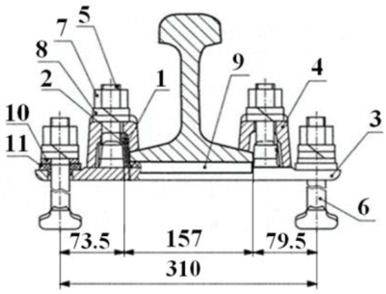

Fig. 2 СКД65-Б fastener structure

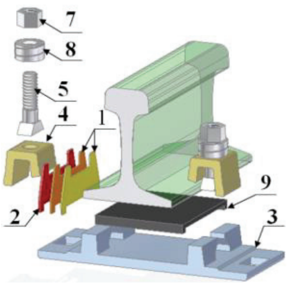

Fig. 3 3D-scheme of СКД65-Б fastener knot

Figs. 1-2 show: *1* – adjusting cards of 2 mm thick; *2* – adjusting card of 3 mm thick; *3* – metal lining; *4* terminals (2 pcs); *5* – bolts (2 pcs); *6* – bolts (2 pcs); *7* – nuts (4 pcs); *8* – double-thread washer (4 pcs); *9* – gasket; *10* –flat washer (2 pcs); *11* – insulating sleeve (2pcs).

Two curved sections of the track with 350 m radius of curves were selected. In one section, RSG was laid on wooden sleepers with Д0 fastener, and in the other section, RSG was laid on reinforced concrete sleepers with СКД65-Б fastener. Track gauge measurements have been performed from the time of the two RSGs laying for five months, every 10 m along the entire length of the curve. The average values of the track width change in two track sections with fasteners Д0 and СКД65-Б for five months of operation are shown in Figs. 4-5.

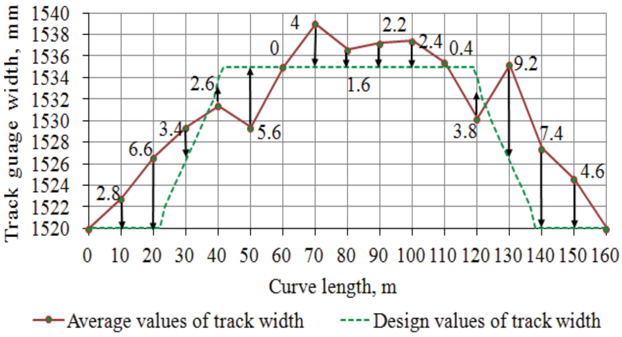

Fig. 4 Track gauge change on wooden sleepers with Д0 fastener for five months

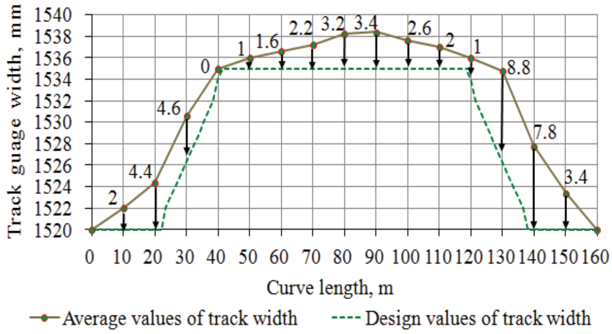

Fig. 5 Track gauge change on reinforced concrete sleepers with СКД65-Б fastener for five months

The results of observations for the track gauge width change in track sections with Д0 and СКД65-Б fasteners, depending on the time parameter, presented as a pair of coordinates « x » and « y », were approximated. The law of the track gauge width change on wooden and reinforced concrete sleepers in a curve of 350 m radius can be described by the function:

$$y = ax + b \, , \tag{3}$$

where a , b - constant parameters.

The function parameters (3), according to smallest squares [17], can be described with the following system of equations:

$$\begin{cases} a\sum_{i=1}^{n} x_i^2 + b\sum_{i=1}^{n} x_i = \sum_{i=1}^{n} x_i y_i \, , \\ a\sum_{i=1}^{n} x_i + nb = \sum_{i=1}^{n} y_i \end{cases} , \tag{4}$$

where x_i , y_i - measured coordinates of any i -point; n - number of points with measured coordinates.

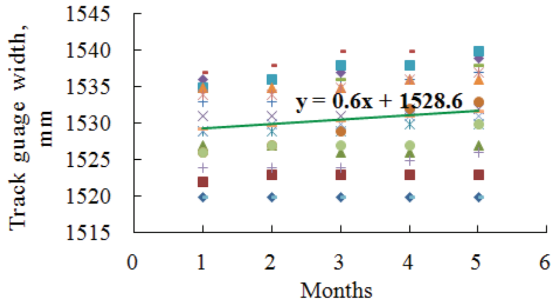

Fig. 6 Approximation of the change in the track gauge width on wooden sleepers for five months

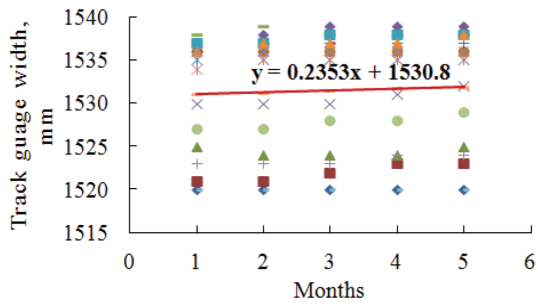

Fig. 7 Approximation of the change in the track gauge width on reinforced concrete sleepers for five months

According to the results of approximation by method [17] in Figs. 6 and 7, it can be seen that the change in the track gauge width with fasteners Д0 and СКД65-Б is linear.

4. Variance Analysis of the Factors Influence on the Change of the Track Gauge Width on Wooden and Reinforced Concrete Sleepers

During measurements in each section, additional factors were investigated, which probable appearance could affect the change in the track gauge width. In the case of RSG with wooden sleepers, the influence of the factors of lateral wear of the outer rail line and the nominal angle of rail inclination loss were observed, caused by the indentation of the metal lining into the body of the wooden sleeper. In the case of RSGs with reinforced concrete sleepers, there was mainly the change in the track width conditioned by the intense lateral wear of the outer rail line. This is due to the increased train load (75… 130 kN) on the track in the horizontal plane, which is typical for curved sections of the track R ≤ 350 m [1, 18].

For a visual representation of the factors of lateral wear of the head of the outer rail line and the nominal angle of rail inclination loss on wooden sleepers, the diagrams of mean values of the track gauge width change were constructed, depending on the influence of these factors (Figs. 8-9).

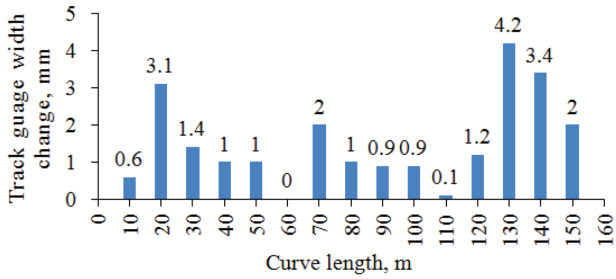

Fig. 8 Lateral wear influence on the track gauge width change

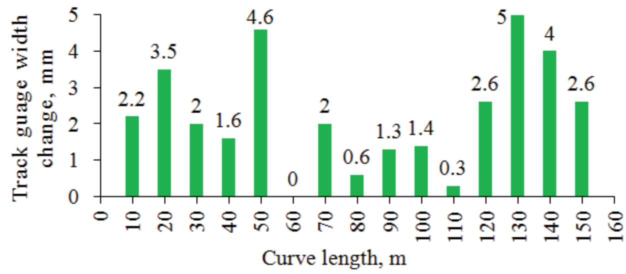

Fig. 9 Influence of the nominal angle of rail inclination loss on the track gauge width change

According to these diagrams (Fig. 8-9) it can be clearly seen that the influence of the nominal angle of rail inclination loss at each point of measurement of the track gauge width shows a much greater value than the lateral wear of the rail head. In the study of the influence of the nominal angle of rail inclination loss and the lateral wear of the rail head on the change of the track gauge width in a curve with radius of 350 m, all observations are presented in the form of a matrix [17].

The arithmetical mean of the entire set of observations:

$$\overline{X} = \frac{1}{n}\sum_{j=1}^{p}\sum_{i=1}^{q_j} X_{ij}, \tag{5}$$

where j - is the factor level number; p - number of factor levels; i - observation number; q_j - number of observations for j factor level; X_{ij} - meaning of the investigated value; n - total number of observations:

$$n = \sum_{j=1}^{p} q_j. \tag{6}$$

Arithmetical mean of the observation of j level:

$$\overline{X_j} = \frac{1}{q_j}\sum_{i=1}^{q_j} X_{ij}. \quad (7)$$

Factor scattering, i.e. the scattering of meanings of the observed value caused by the change in the factor level, is determined by the formula:

$$Q_f = \sum_{j=1}^{p}\left[q_j\left(\overline{X} - \overline{X_j}\right)^2\right]. \quad (8)$$

Residual scattering is the scattering due to unaccounted factors, characterizes differences in observations for one level:

$$Q_r = \sum_{j=1}^{p} Q_{rj}; \quad (9)$$

$$Q_{rj} = \sum_{i=1}^{q_i}\left(\overline{X_j} - X_{ij}\right)^2. \quad (10)$$

As a control for calculations performance, the general scattering acts:

$$Q = Q_f + Q_r. \quad (11)$$

Factorial and residual variance are:

$$\sigma_f = \frac{Q_f}{k_1}; \quad (12)$$

$$\sigma_r = \frac{Q_r}{k_2}, \quad (13)$$

where k_1, k_2 - degrees of freedom:

$$k_1 = p - 1; \quad (14)$$

$$k_2 = n - p. \quad (15)$$

The assessment of the degree of the studied factor influence on the observed value is a criterion *F*, which is determined from the expression:

$$F = \frac{\sigma_f}{\sigma_r}. \quad (16)$$

The greater the value of the criterion F, the stronger the influence of the investigated factor. According to the level of significance α [17] and degrees of freedom k_1 and k_2 there is such a critical value $F_{critical} = f\left(\alpha, k_1, k_2\right)$ that, under the condition $F < F_{critical}$, the investigated factor does not affect the observed value at all [19].

The results of the variance analysis on the influence of factors (rail inclination loss and lateral wear of the rail head) on the change of track gauge width on wooden sleepers are shown in the form of a table (Table).

Comparing obtained values of criteria with critical ones (Table), it can be seen that the influence of factors of the rail inclination loss and the lateral wear of the rail head significantly affects the track gauge width in a curve with the radius of 350 m with wooden sleepers.

According to the regulatory documents of the Ukrainian railways [20], the track width standard in circular curves with radii from 200 m to 450 m is 1535 mm. At the same time, in the presence of lateral wear of rail heads in the curves, the magnitude of deviation in the extension that needs elimination can be increased for the amount of actual wear of the inner face of the rail head of the outer line. At the same time, the width of the track gauge at curves with radii less than 650 m should not exceed 1545 mm. Assuming that the track gauge will change before its adjustment as well, using functions simultaneously (see Figs. 1-2), obtained by approximation, one can predict the time when the following track gauge adjustments will be required for wooden sleepers and reinforced concrete sleepers.

Table

Factors influence on the change of rail gauge width on wooden sleepers in a curve of radius 350 m

Parameters	Rail inclination loss					Lateral wear of a rail head			
$\overline{X}$	2,71					2,41			
$\overline{X}_j$	0,18	1,75	2,6	4,033	5	0,55	1,65	3,25	4,2
q_j	5	6	2	3	1	10	4	2	1
Q_f	48,122					78,633			
$Q_{r\,j}$	0,288	0,675	0	0,607	0	1,965	0,51	0,045	0
Q_r	1,570					2,520			
k_1	4					3			
k_2	12					13			
σ_f	12,031					13,871			
σ_r	0,131					0,194			
F	**91,973**					**71,556**			
$F_{critical}$	3,26					3,415			

In order not to penalize this curve after the track measurement car, the track width is made to correspond to the second degree of indentation [21], i.e. the track width of a circular curve along the entire length is 1543 mm, both on wooden and concrete sleepers. Taking this into account, a frequency graph of the track gauge adjustment in a curve of radius 350 m for wooden sleepers and reinforced concrete sleepers is presented in a visual form (Fig. 10).

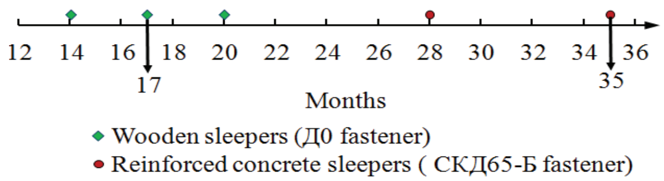

Fig. 10 Frequency of a track width adjustment in a curve of 350 m with wooden and reinforced concrete sleepers

According to the data (Fig. 10), it is established that after the first adjustment of the track width in a curve with wooden sleepers, the next adjustment is made every 3 months, and in a curve with concrete sleepers the adjustment is made every 7 months. The frequent cases of track gauge width adjustment on wooden sleepers can be clearly explained by studies [7, 9]. After the third track gauge adjustment with wooden sleepers, the holes for spike fastening (fastener Д0) have already been worked out, which practically makes it impossible to press the rail to the sub-base tightly. Taking into account the above studies, it is established that with the appearance of СКД65-Б fastener, it becomes possible to increase the range of reinforced concrete sleepers use in the mountains, including difficult operating conditions significantly. According to studies [5, 12, 22], this is the way to create a seamless structure in curves with radii of 350-200 m, as well as a reliable provision of railway transit services for Ukraine-European Union [23] with further use of the newest and perspective rail fasteners [24].

5. Conclusions

The method and algorithm for determining the tapping section for the track gauge extension on reinforced concrete sleepers in curves with radii less than 350 m are developed. This technique is versatile because it can determine the tapping section for the track gauge extension for transient curves of different radii and length when passing from a straight section to a curve. This makes it possible to use reinforced concrete sleepers in curves with radii less than 350 m, with an ordinary scheme of laying for straight sections. At the same time, this technique can be used for European standards of retaining the track geometry in the plane.

DNURT has developed the design of СКД65-Б rail fastener. This allows adjusting the track gauge width in a curve section, namely, gradually extend the track gauge from 0 mm to 14 mm, and to narrow it from 0 mm to 28 mm. This allows us to adjust the track width with accuracy up to 1 mm when the rails are worn during operation. The principle of the structure operation of СКД65-Б fastener is based on the above-described method of gradual tapping of rail track extension within the transition curve. This will reduce the operational cost of this track structure maintenance in comparison with the existing tracks on wooden sleepers in curved sections of a small radius ($R \leq 350$ m).

Studies have been carried out, on the basis of which the comparative assessment of the impact of the track gauge change with the use of Д0 fastener (wooden sleepers) and СКД65-Б fastener (reinforced concrete sleepers) was performed. Two curved sections of the track with the same load capacity and radii of curves of 350 m were selected. On one section, the RSG on wooden sleepers with Д0 fastener was laid, on the other section, RSG on reinforced concrete sleepers with СКД65-Б fastener was laid.

The empirical dependence of the process of changing the track gauge width is presented, as well as the periodicity of its adjustment on reinforced concrete sleepers and wooden sleepers in a curve with a radius of 350 m. It is established that the track gauge width adjustment on wooden sleepers is made every 3 months, and in a curve with concrete sleepers' adjustment is performed every 7 months. The main factor influencing the intensive track extension on wooden sleepers is the rail inclination loss, which value in each of the track gauge measurement points is much greater than the value of the rail head lateral wear. As for the curve with a radius of 350 m on reinforced concrete sleepers concerned, the track width changes due to lateral wear of the outer rail line, which can be promptly corrected using the above mentioned СКД65-Б fastener.

Based on the above work and obtained results, it is possible to increase the range of reinforced concrete sleepers use in the mountains significantly, including difficult operating conditions. This is the way to create a seamless structure in curves with radii of 350 ÷ 200 m, ensuring the reliable operation of the railway track and the safety of train traffic.

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