Maintenance Reliability of Railway Curves Using Their Design Parameters

Mykola Kurhan, Dmytro Kurhan, Nelya Hmelevska

Department of Transport Infrastructure, Dnipro National University of Railway Transport named after Academician V. Lazaryan
Lazaryan st. 2, 49010 Dnipro, Ukraine
{mykolakurhan, kurhan.d, hmelevnela}@diit.edu.ua

Abstract: Based on the conducted monitoring of the railway track operation, it is shown, that most curves fail to meet the source nameplate data. Proposals have been developed to reduce the intensity of the track disorder, due to the reduction of curve parameters to the normative requirements, operating in Ukraine. Recommendations obtained in this work will contribute to the effectiveness of design decisions, determine the quality of the reconstruction projects in general and the expediency of its implementation in particular, they will be useful for carrying out activities to improve the smoothness of trains movement, increase the speed and level of travel comfort, in the curved tracks, especially in the future development of high-speed train implementations.

Keywords: railway; railway curve; survey of curves; accuracy assessment; reliability

1 Introduction

Since the beginning of railways, research was carried out in all industrialized countries, in order to increase the speed of trains. The maximum speed of trains was and remains the measurement of the technical progress and economic development of a country. A distinctive point dividing the usual movement from the high-speed one, was the round figure of 100 mp/h (160.9 km/h).

Setting the maximum permissible speed according to the parameters and the state of curves is a complex task, the effectiveness of the high-speed movement implementation of passenger trains, depends on a correct solution.

The methods used today to determine the optimal parameters of the curves, are imperfect, since subjectivity, the performer's qualifications and other factors are introduced into the end result. The geometric parameters of curves indicated on the longitudinal profile, often do not coincide with the actual data.

The reconstruction of the section, with placing the track centerline into the project position, in the profile and the plan with the restoration of the design radii, is especially relevant. In this case, the parameters of the track must correspond to the maximum speed, safety, smoothness, comfort and the costs of restructuring the track within the rational parameters must reconcile. Today, the maintenance of the track, in the absence of sufficient funding and other objective reasons, are not fully implemented, and therefore, the reliability to keep parameter values of the plan, within the time limits that characterizes the ability to perform the necessary functions in specified operating conditions, is reduced.

Considering the reliability of a technical object, in a broad sense, the authors mean the ability of the railway track to be trouble-free, in operation, during the life cycle, due to the time, in the execution of the set task. In good working order, the track must meet all the requirements established for it, by normative-technical and design documentation. The inconsistency of at least one of the requirements, defines an object into the category, of defective.

The purpose of this work is to analyze the existing methods of a survey of horizontal curves, study the impact of the errors in measuring the plan parameters, on the permissible speed of trains traffic and development proposals for reducing the intensity of the track disorder, by bringing the parameters of curves to regulatory requirements operating in Ukraine, for the future directions of implementation of the high-speed train implementation.

2 Analysis of Current Literature

Currently, there are known methods for a plan survey of a railway, each of which, has advantages and disadvantages. Thus, in works [1-3] an analysis of the plan survey accuracy for the railway track is presented. The authors come to the conclusion, that at a full survey by the method of arrows, it is necessary to determine the coordinates of individual points in 100-150 m (tacheometric, GPS survey, intersection sights from the reference stations). Then, the disadvantages of the survey of arrows, associated with an increasing error, will be eliminated. At the same time, the coordinates of individual points adjusted in the arrow measurements, will also become more accurate.

Article [2] discusses the question of determining the horizontal curvature of a railway track, noting that this is most often done on the basis of the measured versines from the chord stretched along the track. Further usage of this method would not be substantiated if there was a direct method of determining the curvature. A new method of determining the horizontal curvature, which is based on changing the angles of slope to a chord in the Cartesian coordinate system [4], is considered. The verification of the proposed method was conducted on a clearly defined geometric track system consisting of a circular curve and two symmetrically located transitional curves.

It should be noted that the measurement of versines, historically, is the basis for the diagnostic methods relating to the evaluation of the geometric state of railways [5-9]. At the same time, it is deemed necessary to ensure a radical improvement of the existing situation by the method of mobile satellite measurements [10-12]. In Poland, for example, it is a National spatial frame of reference PL 2000. The result of such measurements is a set of numbers that after appropriate processing, form a set of coordinates in the corresponding Cartesian system.

In addition to the American GPS and Russian Glonass, which are present on the market, it is planned to use the Galileo satellite network, which is currently being developed in Europe. Galileo Global Navigation Satellite System is created by the European Union to ensure the independence of member countries, in the field of coordinate and navigation support [13].

Today, the business network of stations, in the improvement of positioning on the Earth, the TNT GNSS Network, is actively operating in the territory of Ukraine, which provides users with access to the GNSS data, via the Internet. Also, there the possibility of access to the correction information, in the RTCM format according to the NTRIP protocol and within the operational area of stations, it is possible to execute the work in RTK mode (Real-Time Kinematic), with an accuracy of 1 mm [14].

Each time, with the next appearance of an updated GPS positioning system, Scientists conduct research in the direction of determining the coordinates of machines in motion, using these systems, but without strengthening them in base stations on Earth. But still, the results of these studies do not allow determination of the position of the track, with sufficient accuracy to perform work on the surfacing [15].

The track surfacing is one of the labor-intensive processes and at the same time, the most significant, since the operational characteristics depends on the track surfacing (smoothness of movement, the traveling speed, etc.), the safety of movement, the costs of current repair and maintenance [16-22]. Track surfacing is carried out with all types of repair, reconstruction and new construction.

An analysis of the plan of the line in the directions of the accelerated train traffic (141-160 km/h) in Ukraine showed that there was a correlation dependence between the specific gravity of the lengths of curves and the percentage in the implementation of the maximum traffic speed (Fig. 1).

During operation, train loads affect the railway track. Over time, the deformation accumulates, the track disorders begin to be observed which cause operating restrictions that directly affect the speed and safety of motion. For example, the authors in [23] demonstrated the results of the analysis of the deterioration of the tram lines geometry. When performing the repair work, it is necessary to bring the track to the design coordinate position, both in installing a new four-track grating and with current repairs by correctional machines.

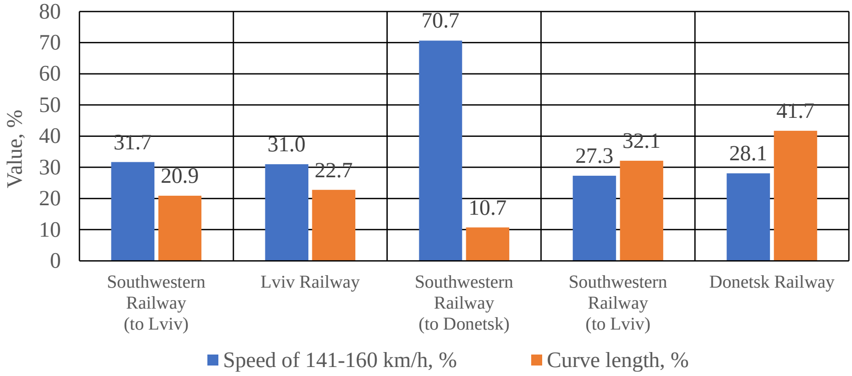

Figure 1

Realization of speed of 141-160 km/h in the directions of accelerated train traffic

3 Comparison of Curves Characteristics

In accordance with the requirements of the instructions (for Ukraine it's CP-0269 [24] and CP-0236 [25]) before the implementation of high-speed trains, railway tracks, rolling stock and other railways service should be brought to a state that provides trains with allowed speeds. Consequently, there is a task of assessing the state of each curve, to ensure the safety, smoothness of the movement and travel comfort.

To compare the full-scale position of the curve with the design one, a technical passport is drawn up for each curve. Authors present an analysis of the passport data for the period from 2017 to 2021 for the curve located on the odd track on the Slavhorod-Novohupalivka section at the regional branch "Prydniprovska Railway", 1058-1059 km. The source data of the curve is obtained by the survey of the method of arrows from a 20-meter chord (versines) and elevation of the outer rail at the same points (Fig. 2).

The passport specifications of each curve must meet the following requirements:

requirement 1 Compliance with the recommendations of existing regulatory documents on the construction and maintenance of the track and implementation of allowed permissible speeds

requirement 2 The position of the curve in the plan may differ from the existing no more than extremely possible track shifts, limited by overall, technical, technological and other requirements *requirement 3* Passport specifications of the curve construction (by curvature, the elevation of the outer rail, the length of transient curves) should provide the rational rates of the non-compensated acceleration (α , m/s^2), the speed of its change (ψ , m/s^3) and relocation of elevation of the outer rail (i_g , ‰) at the allowed and actual speeds of trains

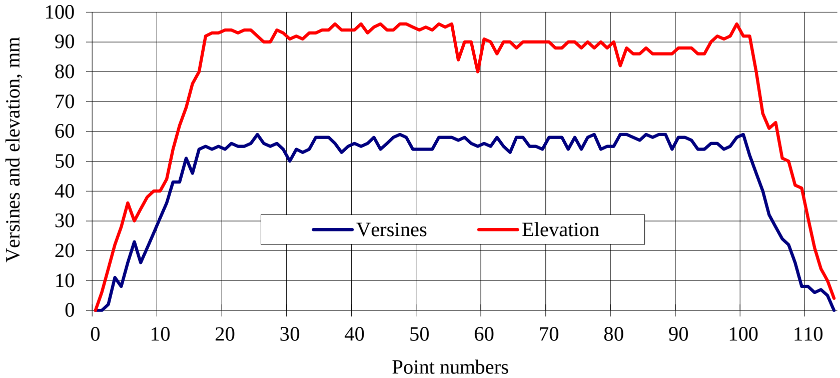

Figure 2

Versines and elevation of outer rail in curves in accordance with date from 01.01.2021

The method of research involves checking the passport specifications of the curves. If the existing curve parameters differ from requirements (1-3), then the rational parameters of the curve are calculated for a given range of speeds that ensure the implementation of existing normative documents, optimization of the power interaction between rolling stock and tracks with minimum displacement and the elevation of the outer rail.

The calculated design passport specifications of the curve after approval by the track service must be implemented in planned repair works or reconstruction of the track.

Verification of compliance with the requirement 1. The curve is considered to be dynamically smooth, if the deviation in the versines do not exceed the nominal values, that is the difference of versines in adjacent points in 10 m at the length of the chord 20 m.

On the existing railways, the form of the transition curve remains in the form of a radioidal spiral with a linear relocation of the superelevation and the curvature, and the permissible traffic speed is allowed [24], depending on the steepness of the relocation. For the maximum permissible speed of 120 km/h, the steepness of the relocation of the superelevation (mm/m) is taken in the range of more than 0.7 to 1.0 incl.

According to the passport of the curve, the radius of the existing curve is 867 m, the length of transition curves is 150 and 140 meters, superelevation is 95 mm.

The greatest difference of adjacent versines of an outer rail in a circular curve 8 mm, and the greatest deviations from the uniform growth of versines on the transition curves is 5 mm [24].

Thus, from Fig. 3, it follows that within the transition curves, that is, deviations from uniform growth of versines on a transition curve, reach 8-9 mm at a permissible 5 mm.

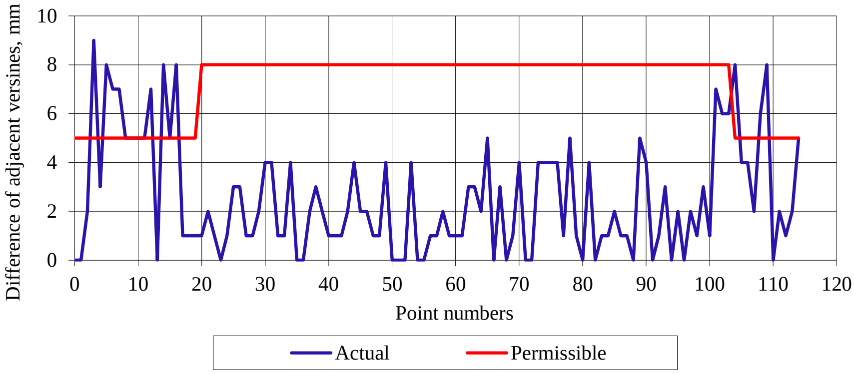

Figure 3
Difference of adjacent versines: actual and permissible

According to [24], for a speed of 120 km/h, the maximum permissible steepness of the relocation of the superelevation in the curve is 1.0 mm/m. From the analysis of Fig. 4, it follows that on transition curves and in a circular curve there is an excess of the gradient of 1.0 mm/m, which determines the state of the curve that does not provide smoothness and comfort of the travel.

The parameters of the curves are updated annually by measuring the magnitudes of the versines and elevation of the outer rail. By measured versines, the angle of rotation, radius and all elements of the curve are determined. The measure of the angle of rotation does not depend on the radius of the curve and the degree of its disorder and is constant for this curve. The monitoring of surveying works on the curve, which is taken for an example at the Slavhorod-Novohupalivka section, should be admitted unsatisfactory (Table 1), since the angle of rotation of the curve for five years (from 2017 to 2021) differs by 5-8%, the radius of the curve by 6-10%, and the length of the curve is 3-6% of the average number.

Compliance verification with requirements 2. When reconstructing the track, the correction of horizontal curves is performed with the restoration of the design radii and bringing the lengths of transition curves to the allowed norms.

Since the existing curve parameters are different from the above requirements (1-3), then the rational parameters of the curve are calculated to provide a allowed maximum speed of passenger trains 120 km/h. As options, one-, two- and three-radius curves were considered (Table 2).

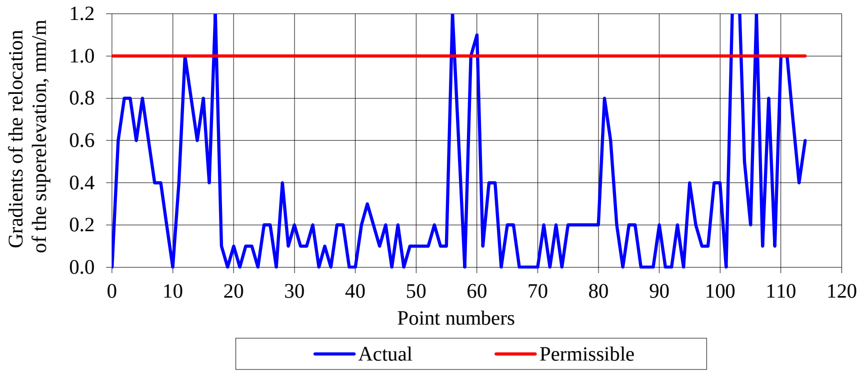

Figure 4

Gradients of the relocation of the superelevation at the points of the curve survey

Table 1

The value of the curve parameters and the appropriate permissible traffic speed

Curve parameters	The values of the curve parameters obtained in different years				
	2017	2018	2019	2020	2021
The angle of rotation	56°23'	64°09'	63°55'	58°53'	62°17'
Radius, m	998	858	857	948	889
1^{st} transition (chlotoide), m	40	110	140	130	190
Circular, m	892.04	825.62	821.07	839.36	816.35
2^{nd} transition (chlotoide), m	140	160	130	140	110
Superelevation, mm	35	85	85	75	85
The sum of landslides	4920	5598	5578	5139	5435

In determining the design parameters of the curve, the criterion of working cost was used to reorganize the plan of a line. In this case, when optimizing, the cost of track alignment, relaying of a track, additional ballast, the transfer of the contact network and SCB devices, additional volumes of heaping the roadbed are taken into consideration. The need for certain additional works was determined programmatically depending on the displacement value at the specified point of the curve.

Total cost of works on the restructuring of the curve was performed by the equation:

$$K = \sum_{i=1}^{4} a_i l_i + \sum_{i=5}^{7} a_i l_i + \sum_{i=8}^{10} a_i Q_i \qquad (1)$$

where $a_1 \dots a_4$ – costs on displacement of the existing track centerline respectively up to 60 mm, 61-120 mm, 121-250 mm and more than 250 mm; $l_1 \dots l_4$ – length of sections with a corresponding range of landslides; $a_5 \dots a_7$ – expenses respectively to the relaying of the permanent way, transferring the network, SCB devices; $l_5 \dots l_7$ – length of sections of relaying tracks, transferring the contact network, SCB cables; $a_8 \dots a_{10}$ – the cost of the 1 m^3 ballast, soil for expanding the existing roadbed and soil for heaping the roadbed on a new route; $Q_8 \dots Q_{10}$ – the volume of ballast, soil for expanding the existing roadbed and soil for heaping the new roadbed.

When track alignment to a distance of more than 60 mm, additional volumes of work arise that are related to the works on the contact network and the filling up of ballast will occur. And if the displacement exceeds the given value (for example a_4), then instead of costs for alignment, the cost of relaying tracks, transferring the contact network and SCS devices are calculated.

Volume cost indicators on the options in reorganizing the plan of a line are given in Table 2.

From analysis of Table 2, it follows that, taking into account the financial position, the option of a three-radius curve, at which the track surfacing is provided within the main site of the roadbed with minimal expenses.

Verification of compliance with the requirement 3. Controlled values of the curve according to which evaluation of the actual parameters of the curve are:

- The magnitude of the horizontal acceleration (α), calculated on the entire curve according to the actual values of the curvature and elevation of the outer rail with regard to their local deviations with a length of not less than 30 m
- The rate of change of non-compensated acceleration on the sections of variable curvature (ψ, m/s^3)
- The steepness of the relocation of the superelevation (i_g, ‰) in transient curves

Figure 5 shows graphs of non-compensated accelerations and the speed of their change along the curve. From the graphs it follows that at a maximum speed of 120 km/h, after correction of the curve, the conditions of not exceeding the speed of the non-compensated acceleration on the sections of variable curvature $\psi \leq 0.6$ m/s^3, and non-compensated acceleration α on the section from 55^{th} to 100^{th} point reach 0.75-0.80 m/s^2.

Table 2

Volume cost indicators on the options

Radius of curve (R_i), m	Transition curves (L_i), m	Superelevation (h_i), mm	Maximum displacement, mm	The sum of landslides, mm	Costs, Euro
R_1=889	L_1=190; L_2=110	h_1=85	+ 277 - 178	11972	3679
R_1=899; R_2=879	L_1=160; L_2=80; L_3=140	h_1=80; h_2=85	+ 83 - 77	3852	731
R_1=902; R_2=889; R_3=877	L_1=160; L_2=30; L_3=40; L_4=140	h_1=80; h_2=85; h_3=85	+ 47 - 61	1876	309

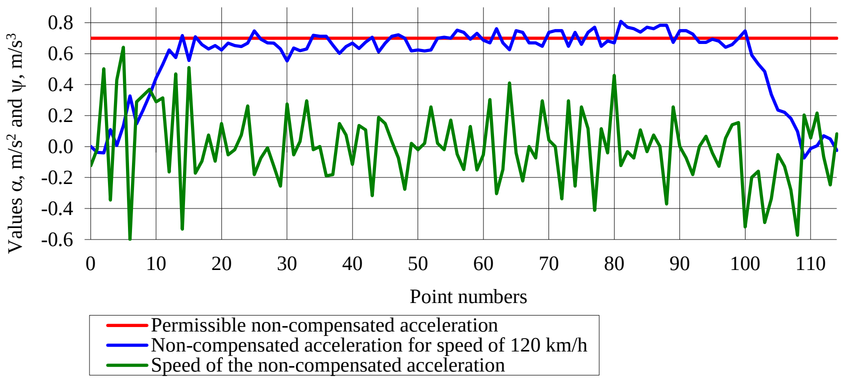

Figure 5

Non-compensated acceleration and speed of their change along the curve

The comparison of various methods of the survey for one of the curves on the Synelnikove – Chapline, Regional Branch "Prydniprovska railway" [1] was performed. The survey was performed by the method of arrows, Honikberg's method and coordinate one, with the use of an electronic tacheometer.

Comparison of the results in straightening the curves according to the source data obtained by various methods of the survey is shown in Table 3.

As it can be seen from Table. 3, permissible speeds by various methods of the survey are different. From this and other examples it follows that for the proper solution to the issues of reconstruction of the track and track buildings in order to provide the speed of 161-200 km/h in the internal transport corridors, it is necessary to conduct the works on the conditioning of curves and establishing a real permissible speed of movement on them at the current level.

Table 3
The value of the curve parameters and the corresponding permissible speed of motion

Curve parameters and the permissible speed	The values of the curve parameters obtained by different methods of the survey		
	Method of arrows	Honikberg's method	Coordinate survey
The angle of rotation	15°09.6'	14°47'	14°49.5'
Radius, m	1156	1110	1156
1st transition (chlotoide), m	90	60	100
Circular, m	199.29	226.40	197.03
2nd transition (chlotoide), m	100	60	110
Maximumpermissible speed, km/h	130	120	126
Extreme landslides, mm	+ 23 - 43	+ 24 - 106	+ 15 - 84

Conclusions

To date, there are many techniques that are used to measure the parameters and the states of curves. It is the existence of various techniques that have practical application, suggests that each of them has its own advantages and disadvantages. To select a technique, it is necessary to have both a statistical and a mathematical justification.

Comparing the results of the curve survey by various methods, it can be established, how much they differ from each other, but, it is impossible to determine their differences, in relation to the absolutely correct values, since the exact position of the curve remains unknown. It is also obvious that the accuracy of the results will depend, not only on the parameters of the measuring devices and the ability of the executors, but also on the methodology that defines the technology of measurement and the needed mathematical transformations of the data obtained, for example, in the curvature of a curve.

The most effective method is the method of the survey, by a track-measuring car, correctional-tamping-gauging machines, as well as, a survey method using GPS sensors and a survey using track-measuring trucks. When they are used simultaneously, a plan survey and longitudinal profile of the railway track are carried out. But each of them has their inherent advantages and disadvantages. The most accurate method, with the greatest degree of process automation, can be considered a survey method using GPS sensors, but for this accuracy, it requires a developed network of baseline GPS stations located on Earth.

For all curves that limit the speed of movement, as well as, those that are maintained with deviations, an on-site inspection, with the fulfillment of the complete calculation cycle, for their certification, must be carried out.

The certification of curves will contribute to reducing the intensity of the railway disorders, reducing labor costs in maintaining the track in the plan, increasing the smoothness and comfort of riding.

Today, the business network of stations, for the improvment of positioning on Earth, is the TNT GNSS Network, is actively operating in the territory of Ukraine and provides users with direct access to GNSS data, via the Internet. Without significantly upgrading the technique, for the survey and track surfacing, one can start certification and track surfacing, using the global coordinate system. In the future, the usage and development of this network and prospects, are open for full certification of the track, in the global coordinate system, the creation of a virtual reference system and the track surfacing preparation, by heavy machines, including project coordinates, without the need for physical measurement visits.

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