V. Jóvér[1],
orcid.org/0000-0003-4593-853X,
M. Sysyn[2],
orcid.org/0000-0001-6893-0018,
J. Liu[3],
orcid.org/0000-0002-4779-7761,
S. Fischer*[1],
orcid.org/0000-0001-7298-9960

1 — Széchenyi István University, Győr, Hungary
2 — Institute of Railway Systems and Public Transport, TU Dresden, Dresden, the Federal Republic of Germany
3 — Southwest Jiaotong University, Chengdu, the People's Republic of China
* Corresponding author e-mail: fischersz@sze.hu

GEOMETRY VARIATION OF BALLASTED RAILWAY TRACKS DUE TO WEATHER CONDITIONS

Purpose. Investigate and establish the relationship between track geometry measurements and weather conditions to determine the parameters that influence the lifetime of railway tracks' superstructure system. The study of ballasted beds of railway tracks is very important for operation and maintenance in case of main lines, industrial sidings and mine transport.

Methodology. Determination of the annual load of the selected section based on the regulations. Compari of the track parameters measurements made by TrackScan 4.01 instrument in different seasons and temperatures. Among the parameters measured by the instrument, the track gauge, alignment, longitudinal level, and superelevation parameters are considered and analyzed in this article. Since the main lines' traffic are permanently loaded with passenger and freight transport and the industrial sidings and mine tracks are used in the production process, the examinations can only be done on tramway tracks during the standstills at night. The results of these measurement on tramway tracks can help to understand the identify of railway tracks' lifetime and can be used in mainlines, industrial and mining railway tracks.

Findings. The change in the average values of selected track geometrical parameters is analyzed, considering the typical weather conditions. Based on the measurement and results, there is an evident connection between the evaluated results of track geometry measurements and the change in weather conditions.

Originality. Finding the relationship between changes in track geometry values and weather conditions on the basis of an evaluation of track geometry measurements taken on average every third month.

Practical value. The results can then be used as input data for determining the service life of the track superstructure in the case of tramways, mainlines, industrial and mining railway tracks.

Keywords: *railway transport, deterioration, ballasted track, traffic load, track gauge*

Introduction. Nowadays, examining the deterioration of railway tracks is critical, not only from the technical but also from economic viewpoints: using the available resources to develop the infrastructure as efficiently as possible is necessary. The deterioration of superstructure systems of railway tracks can be characterized by observing the structural deterioration or the degree of change in the track geometry characteristics [1]. In case of structural deterioration, the structural elements like rails, fastenings, sleepers, etc., go to ruin, and they cannot perform their task. On the other hand, geometric deterioration means several geometrical characteristics, for example, track gauge, alignment, superelevation, etc., deviation from the prescribed values. The best case is when various examinations are carried out regularly on time, so it is possible to interpret them together and understand their changes over time.

For this article, a specific superstructure system (ballasted track) was selected, and its traffic load and the changes in its track geometry characteristics will be presented.

The study of ballasted beds of railway tracks is very important for operation and maintenance in case of main lines, industrial sidings and mine transport.

Production of ballast material is a significant task, even in Hungary and also all over the world. There are many problematic issues related to selecting adequate quarries because there are more locations with appropriate rock materials with required rock physics characteristics; however, the places are related to, e.g., Natura 2000 (nature) reservation. Therefore, it can also be an issue if some part of the quarry belongs to this reservation area, which is a real problem in Hungary [2]. In this way, the crushed stone material producers can "suffer" from the requirements of ready railway ballast material to meet customers' demands.

Hungary has two main types of rocks available with variant quantities for railway ballast: andesite and basalt. First, it has

to be mentioned that the most appropriate type — based on construction and operation experience — is granite; however, Hungary does not have enough quantity from it [3, 4].

Supplying adequate quality crushed stone railway ballast material in the required quantity is crucial and significant in every country. One of the possible options is the production opportunity inside the (own) country; the other is the supply from abroad. In the case of supply, the price of the product is the first factor; however, the transportation costs can reach or exceed the supply costs: 1-ton railway ballast costs approx. 14.6 EUR, the shipping costs by electric train is 0.0025 EUR/ton·km whereas by truck it is 0.014 EUR/ton·km [5, 6]. It means that the ratio between the shipping costs is 1 : 6. The data are given based on 410 HUF/EUR rates.

International researchers dealt with the related issues of railway and road transportation [7, 8], as well as quarry ballast [2, 4, 9]. Naumov, et al. [7] proposes an approach to determine the optimal parameters of production resources in multimodal transport terminals. Saukenova, Oliskevych, et al. [8] investigated the simulation possibilities of cargo delivery by road carrier. Milosevic, et al. [9] have dealt with model-based remote health monitoring of ballast conditions in railway crossing panels considering multibody simulation model which considers the complex wheel-rail interaction in the crossing transition area, while also capturing the dynamic response of the track using a finite element representation of the track structure. Rao, et al. [10] executed finite element analysis regarding structural dynamics on a railway freight wagon. The above-cited papers [7, 8, 10] can be engaged and connected to the transportation of railway ballast material: simulation, optimization of costs, reduction in transport routes, etc. In the "era" of COVID, the Russian-Ukrainian war, the global financial crisis, etc., the prices of fuels, electricity, gas, base, construction materials, and so on, can be increased dramatically. Without continuous optimization, the transportation costs — even on roads and railways — can become more and more expensive,

which modifies the result of the cost-benefit analysis of a construction and/or an investment project anywhere in the world.

Nowadays, railway engineering research (mainly civil engineering and transport infrastructure engineering) related to railway ballast focuses on many issues, e.g., non-exhausting, increasing the resistance against breakage [2, 4, 11], and considering point load test to classify them [12], etc.

Statement of the problem. The main lines' traffic is permanently loaded with passenger and freight transport and the industrial sidings and mine tracks [13, 14] are used in the production process, the examinations can only be done on tramway tracks during the standstills at night. The results of these measurement on tramway tracks can help to understand the identify of railway tracks' lifetime and can be used in main lines, industrial sidings and mine rail transport.

In Budapest, the capital of Hungary, traveling by tramway track is one of the essential parts of public transport. The first tramway line was built in the city in 1887. Despite this, the deterioration, life cycle, and life cycle cost of several superstructure systems are not fully known until this day; their selection and application are mainly based on experience.

In Hungary, seven types of superstructure systems are currently differentiated:
- ballasted track;
- concreted ballasted track;
- concrete slab track;
- ESCRB I. track system;
- ESCRB II. track system;
- ESCRB III. track system;
- 'large slab' ('big panel') superstructure [15].

ESCRB abbreviation means elastically supported continuous rail bedding system; in Hungary, the 'RAFS' abbreviation is applied.

During the execution of each superstructure system, there can be many differences between the rail system, fastening, sleeper, or the type of used covering.

Several factors can influence the lifetime of tramway tracks:
- planning;
- construction;
- traffic;
- effects of the environment;
- track maintenance;
- financing [16].

The ballasted track is the most commonly used superstructure system for railways and light rail transits. The rail system is generally not covered, the rail profile is Vignol or grooved rail, and the fastenings are elastic or inelastic. The material of (cross) sleeper can be wooden, synthetic, or some types of reinforced concrete, and there is ballasted bad.

In the case of railway tracks, there are four types of lifetimes:
- technical (planning) life;
- economic lifetime;
- service lifetime;
- moral lifetime [14].

The technical lifetime of the ballasted superstructure system in the case of railways is 30 years [16]. However, light rail transits are not equivalent to railways: the vehicles travel at lower speeds and have less axle load, too, so it is assumed that their lifetime values are not the same [16]. On the other hand, it can be assumed that several types of lifetimes can be determined.

The purpose of the article is to evaluate the results of the track geometry measurements, which have been made on average every third month since July 2021, and find a relationship between the changes in values of the characteristics and the weather conditions. In the future, these results may provide baseline data for determining the lifetime of ballasted track superstructure system in the case of tramway tracks.

Materials of the article. The selected section which is examined in this article is ballasted track, and it was built in 2002. The applied rail profile is 49E1, with a reinforced concrete slab, (Vossloh) SKL type rail fastening system, and bal-

last bed. There are five level crossings on the section, one has a high traffic load, and there is ESCRB III track system (Fig. 1).

The geometrical configuration (alignment) is mainly straight; there is a 14-meter long ($R = 278$ m) left direction curve and another 34-meter long ($R = 250$ m) right direction curve. Both curves have no transition curve or superelevation. In the first half of the selected section, the track has a 4.4 ‰ gradient; in the second half: a 2.4 and a 3.6 ‰ rise.

During the track section, the patrol walk observed that the rails' running surface has slight corrugation, and the appearance of defects in the rails is moderate. During the visual inspection, it was established that the railway operator applied a rail-grinding machine (Fig. 2) to extend the lifetime of the rails.

The fastenings were not deficient, but their restraint was not visibly reliable in all cases, so it can be assumed that the forces from the rail to the sleeper are not always adequately transmitted; the quantity of force of fastenings is not suitable enough. The reinforced concrete cross sleepers are in good condition: no flaw or detachment could be detected on the upper, visible plane. The ballast bed is exceptionally contaminated, and as a sign of operational deterioration, the rudimentary fragmentation of the ballast can also be observed. There are two places in the selected section where water pockets can be discovered, which refer to the trapped water in the ballast bed and the faults of the substructure.

In the examined section, vehicles of three several tramway lines run for more than 21 hours daily. During peak-traffic hours the following distance is 3–4 minutes, while the average is 7 minutes outside this time interval. Typical vehicles in the section are the CAF URBOS 3/5 vehicle and the TW6000 vehicle. Table 1 shows some of their more essential characteristics.

Methods. To classify a tramway line there are several aspects known:

Fig. 1. The selected section — ballasted track (*own photo*)

Fig. 2. Rail-grinding machine (*own photo*)

- size of traffic;
- length of running vehicles;
- its location in the urban environment;
- the allowed speed for the track [15].

Characterization is often based on traffic size; the classification depends on the annual through-rolled tonnages. The through-rolled axle tonnage is the mass of all crossing vehicles on a given line in one direction in one year. It is determined by multiplying the total number of crossing vehicles on the line and the average of the T0 loading (a serviceable vehicle without crew and passenger) and T3 loading (a serviceable vehicle with staff and maximum passenger capacity) [15, 17].

Four traffic load classes can be differentiated (Table 2). The abbreviation MGT means million gross tons, i. e., the annual through-rolled tonnages.

Based on the calculation described above, the annual through-rolled tonnages of the examined line were calculated and classified into the traffic load class. Therefore, according to the calculations, it can be concluded that in the last four years, the traffic load of the line has been similar; it is a medium-loaded line (Fig. 3).

According to the classification of the length of running vehicles, the selected section is in category two: the length of the vehicles is less than 38 meters, so these are short vehicles [15].

Based on the classification of its location in the urban environment, its category is B/c. It is located in an inner-city environment with road traffic on its side but separated from the road traffic [15, 18].

The examined section has no speed limit; the permitted speed is $V = 50$ km/h. Therefore, according to the allowed speed for the track, it can be classified into speed category III.: $30 < V \le 50$ km/h [15].

The selected section is generally in a suitable, operational condition, there is an average traffic load, and the vehicles can run at the maximum permitted speed.

The tramway tracks and their condition can be characterized most easily by the track geometry parameters and their difference from the prescribed values. According to the current regulations, the planners of the tracks always define a geometry with millimeter accuracy; however, the construction is always constructed with errors of a few millimeters. In Hungary, on the network of BKV PLC., four categories of geometrical dimension limits can be distinguished for the construction and maintenance of tramway tracks:
- A – construction tolerance;
- B – maintenance tolerance;
- C – dispatch tolerance;
- D – stopping operation tolerance [19].

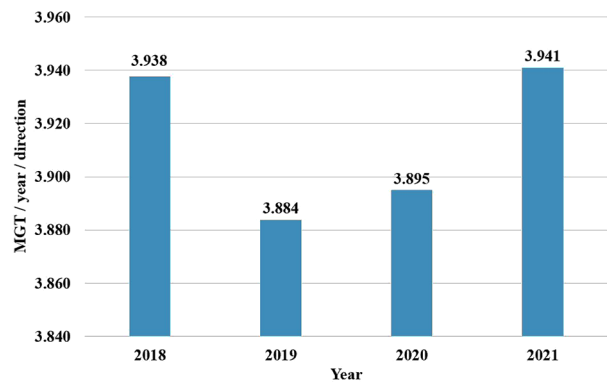For each tolerance category, the deviation from the nominal value in millimeters is defined [19].

Fig. 3. Traffic load of the examined section in the last four years

In the case of a newly constructed tramway track, the contractor must comply with the 'A – construction tolerance'; however, checking compliance with the regulations of the other categories is the operator's responsibility. Based on the track geometry measurements and the evaluation of their results, it becomes possible to decide where and when the application of track maintenance intervention is necessary.

The TrackScan 4.01 instrument was developed and maintained by Metalelektro Méréstechnika Ltd (Fig. 4). This instrument was applied to measure track geometry characteristics on the tramway network of BKV PLC.

During the research, track geometry measurements are also made with the TrackScan 4.01 instrument, on average every three months, during standstill at night. Among the track geometry parameters listed above, the following parameters are considered and analyzed in this article:
- track gauge;
- alignment;
- longitudinal level;
- superelevation.

Track gauge is the distance between the two rails of the track, measured at a given height of the head of the rails between the inner guiding surface perpendicularly in the axis of the track, in the radial direction in the case of a curved track [15, 17].

Superelevation is raising the outside rail to the inside rail to reduce side acceleration in the curve. The change in superelevation is usually made along the entire length of the transition curve [15, 17].

Table 1

Characteristics of vehicles [13]

Type of vehicle	Axle load, kN	Maximum axle load, kN	Number of axles
TW6000	48.5	78.0	8
CAF URBOS 3/5	68.0	102.0	6

Table 2

Traffic load classes [15]

Traffic load class		MGT/year/direction
I./A.	extremely heavy loaded line	>7.5
I./B.	heavily loaded line	5.0–7.5
II.	medium loaded line	2.5–5.0
III.	low loaded line	<2.5

Fig. 4. TrackScan 4.01 instrument (own photo)

The alignment parameter shows the horizontal deviations of rails, its base length is 1350 millimeters, and it is symmetrical. On the other hand, the longitudinal level shows the vertical deviations of rails from the ideal, the base length of measurement is 1510 millimeters, and it also uses a symmetrical basis [15, 17].

The article also tries to construe these parameters together so that the deterioration of the section's superstructure system characteristics can be better understood.

Results. In the previously described section with the ballasted track system, the track geometry measurements were made in different seasons since July 2021. A relationship was assumed between the measurement results and the changes in the seasons and temperature. The typical weather conditions [22] in the week before the measurement were the followings:

1. July 2, 2021: the average daily medium temperature was 24 °C, and there was no precipitation. The average relative humidity was 40 %.

2. September 25, 2021: the average daily medium temperature was 17 °C, and there was no precipitation. The average relative humidity was 65 %.

3. January 15, 2022: the average daily medium temperature was 0 °C, and there was no precipitation. The average relative humidity was 72 %.

4. April 8, 2022: the average daily medium temperature was 10 °C, and significant precipitation fell until the third day before the measurement. The average relative humidity was 65 %.

5. September 14, 2022: the average daily medium temperature was 20 °C, and significant precipitation fell until the fourth and the third day before the measurement. The average relative humidity was 50 %.

After explaining the weather conditions, the analysis of the change in the average values of the track gauge parameter will be presented first.

Fig. 5 shows that the average values of the measurement results change minimally concerning each other. Based on the evaluation of the measurement results in September 2021, the track had a minimal broadening of track gauge compared to the average value in April 2021. In January 2022, the average value of the track gauge parameter is less than in the case of the other four measurements. It can be assumed that the track gauge's narrowing at that time was due to the persistently cold weather. The average values of the measurement results in April 2022 are the highest, but it is important to note that in the days before the measurement, the average daily temperature rose permanently, and the number of hours of sunshine was also high. Although the average temperature in the week before September 2022 was 20 °C, the temperature decreased significantly from the beginning of the month, which may have resulted in a smaller average track gauge than the measurement in September 2021.

The alignment parameter shows the horizontal deviations of rails [15, 17]. These values can have negative or positive signs, so the alignment parameter values were examined in absolute terms to avoid errors.
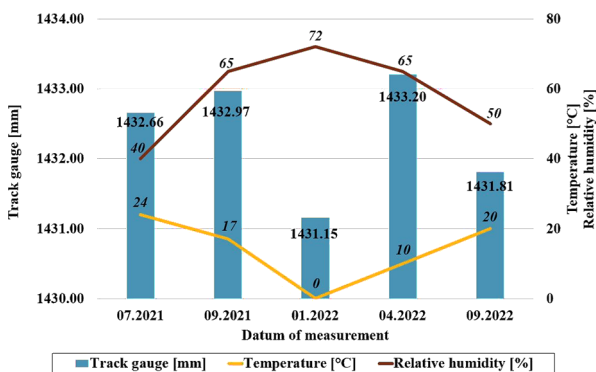
Fig. 6 shows that the right rail's average alignment parameter remained almost the same during the measurement, but it changed significantly in the case of the left rail. The increasing value means that the horizontal deviation of the left rail increases inversely as the temperature decreases.

The longitudinal level parameter shows the vertical deviations of rails from the ideal [15, 17]. These values can also be negative or positive, so to avoid errors, the longitudinal level parameter values were examined in absolute values, similar to the alignment parameters.

Fig. 7 shows that, similarly to the alignment parameter, in the case of the longitudinal level parameter, the deviation between the measurements in the right rail is minimal but significant in the left rail. Based on this, it is clear that when the weather is cooler, the vertical deviation of the left rail is more significant compared with the ideal than in the case of the right rail.

The superelevation values could be positive or negative, depending on whether the outside rail is higher or lower than the inside rail. Therefore, during the evaluation of the measurement results, all of the measured data were shifted by +25.0 millimeters to eliminate the errors caused by the different signs (positive and negative ones).

The deviation of the average values of the superelevation parameter is minimal between the measurements. As shown in Fig. 8, the value is the lowest for the measurement in April 2022, even though the lowest value would have been expected in January, considering the weather conditions. Therefore, based on the evaluation of the measurement results, the change in the average values of the superelevation parameter cannot be linked to the weather conditions.

Furthermore, it is essential to note that the selected section has no planned superelevation. Nevertheless, when the positive and negative values of the superelevation parameters measured and recorded by the TrackScan 4.01 instrument are examined, clear "superelevation" can be identified, which can
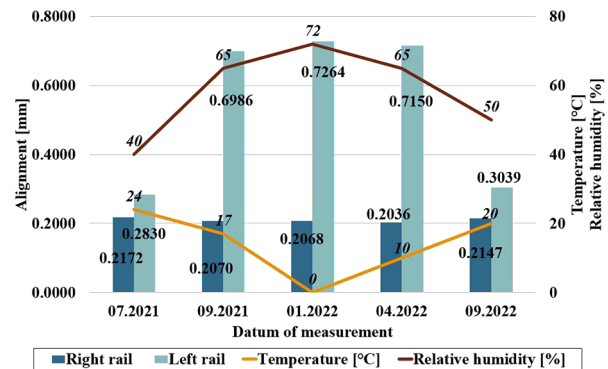

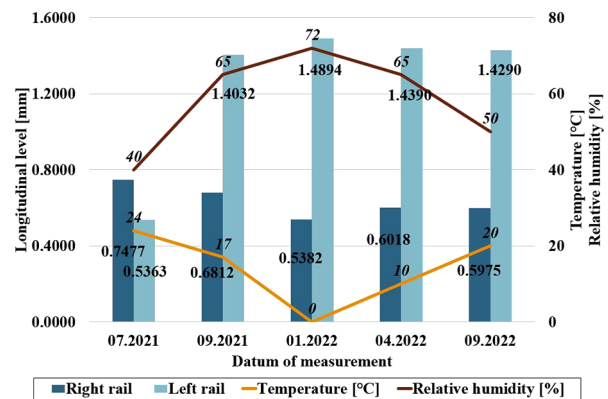*Fig. 6. Average values of the alignment in the selected section*

Fig. 7. Average values of the longitudinal level in the selected section

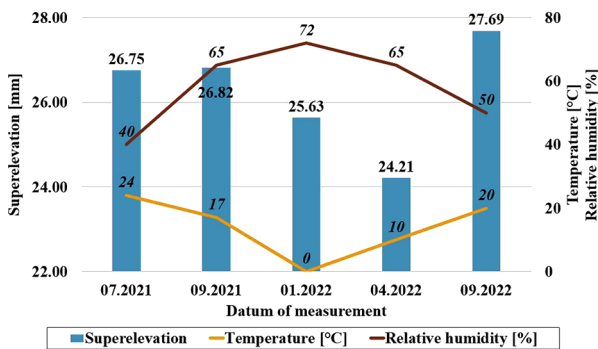*Fig. 5. Average values of the track gauge in the selected section*

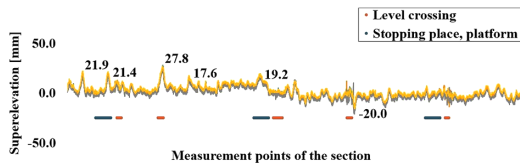*Fig. 8. Average values of the superelevation in the selected section*

Fig. 9. Initial values of the superelevation in the selected section

be problematic (Fig. 9).

The six highest superelevation parameter values are marked in Fig. 9; positive values indicate a higher position of the left rail than the right rail.

In each case, it can be said that these are not just one-time outstanding values, but they are preceded by a gradual increase and followed by a gradual decrease.

For example, the second marked outstanding value (21.4 mm) is located in the platform, just like the fifth marked value (19.2 mm). The third and highest value (27.8 mm) is found in a level crossing, and the fifth value is also (–20.0 mm). Based on the evaluation of the measurement results, it can be established that the deviation of the superelevation parameter from the prescribed value typically appears in platforms and level crossings.

The evaluated results of the five measurements of the examined section are summarized in Table 3 so that the changes in the several track geometry characteristics can also be numerically compared.

There is a clear connection between the evaluated results of the track geometry measurements and the change in weather conditions, except for the average value of the shifted values of the superelevation parameter. Therefore, it is more appropriate to monitor the changes in the values measured and recorded by the instrument over the entire examined section in analyzing the superelevation parameter.

During the winter measurement (January 2022), the other track geometry parameters developed as expected:
- the average values of the track gauge parameter are the smallest in this case;
- the alignment parameter is outstanding;
- the longitudinal level parameter is also outstanding.

For the spring and autumn measurements (September 2021, April 2022, September 2022):
- the evolution of the average values of the track gauge parameter is similar;
- the alignment parameter in the case of the right rail is almost constant, but in the case of the left rail, it is approx. 1.5 times smaller than the winter measurement;
- the longitudinal level parameter is a few percent less than in the case of the winter measurement.

For the summer measurement (July 2022):
- the average value of the track gauge parameter is not the highest; it can be explained that there were many hours of sunshine in the period before the measurements in September 2021 and April 2022;
- the alignment parameter in the case of the left rail is approx. 2.5 times smaller than in the case of the winter measurement;
- the longitudinal level parameter in the case of the left rail is approx. 2.7 times smaller than in the case of the winter measurement.

It is essential to note the difference between the measurement results of the two rails in the case of the alignment and longitudinal level parameters. Based on the evaluation, for both parameters, in almost every case, the values of the left rail are three times higher than the right one. Another critical factor for this result is that the change in the superelevation values over the entire section indicates that the left rail is higher than the right rail in several cases. Therefore, the evaluation of the measurement results allows concluding that the fastenings of the right rail fix the rail better than the left rail. On the other hand, it may indicate that the fastenings of the left rail are no longer working entirely correctly or that the ballasted bed or substructure may also be faulty.

It is necessary to carry out additional measurements and evaluate the measurement results to draw further conclusions about the deterioration of the tramway track geometry.

Conclusions. Nowadays, examining the deterioration of railway tracks is critical from technical and economic viewpoints. Unfortunately the main lines' traffic is permanently loaded with passenger and freight transport and the industrial sidings and mine tracks are used in the production process, so the examinations can only be done on tramway tracks during the standstills at night. The results of these measurement on tramway tracks can help to understand the identify of railway tracks' lifetime and can be used for main lines, industrial sidings and mine rail transport.

For this article, a specific superstructure system (ballasted track) was selected, and its traffic load and the changes in its track geometry characteristics will be presented. Regarding the section, it is generally in a suitable, operational condition, there is an average traffic load, and the vehicles can run at the maximum permitted speed.

During the research, track geometry measurements are made with the TrackScan 4.01 instrument, on average every three months, during standstill at night. The following track geometry parameters were considered and analyzed in this article:
- track gauge;
- alignment;
- longitudinal level;
- superelevation.

Track geometry characteristics of the five measurements

Track geometry characteristics		2021/07	2021/09	2022/01	2022/04	2022/09
Track gauge [mm]		1432.66	1432.97	1431.15	1433.20	1431.81
Alignment, mm	Right rail	0.2172	0.2070	0.2068	0.2036	0.2147
	Left rail	0.2830	0.6986	0.7264	0.7150	0.3039
Longitudinal level, mm	Right rail	0.7477	0.6812	0.5382	0.6018	0.5975
	Left rail	0.5363	1.4032	1.4894	1.4390	1.4290
Superelevation (shifted), mm		26.75	26.82	25.63	24.21	27.69

During the measurements, the track gauge parameter changed almost as expected. Based on the evaluation, for alignment and longitudinal level parameters, in almost every case, the values of the left rail are higher than those of the right rail. Another significant result is that the change in the super-elevation values over the entire section indicates that the left rail is higher than the right rail in several cases.

Based on the measurement and results, there is an evident connection between the evaluated results of track geometry measurements and the change in weather conditions.

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Зміна геометричних параметрів баластних рейкових колій під впливом погодних умов

В. Йовер[1], *М. Сисин*[2], *Я. Лю*[3], *С. Фішер*[*1]

1 — Університет Сечені Іштвана, м. Д'єр, Угорщина
2 — Інститут залізничних систем і громадського транспорту, ТУ Дрезден, м. Дрезден, Федеративна Республіка Німеччина
3 — Південно-західний університет Цзяотун, м. Чэнду, Китайська Народна Республіка
* Автор-кореспондент e-mail: fischersz@sze.hu

Мета. Вивчити та встановити взаємозв'язок між вимірюваннями геометричних характеристик колії та погодними умовами для визначення параметрів, що впливають на термін служби систем верхньої будови рейкових колій. Дослідження баластового шару рейкових колій дуже важливе для експлуатації та обслуговування в разі магістрального, промислового й шахтного рейкового транспорту.

Методика. Визначення річного навантаження обраної ділянки на основі нормативних документів. Порівняння вимірювань характеристик колії, виконаних приладом TrackScan 4.01 у різні пори року та за різних температур. Серед параметрів, що вимірюються приладом, у даній роботі розглянуті та проаналізовані параметри ширини колії, вирівнювання, поздовжнього рівня й надвисотності. Оскільки магістральні шляхи постійно завантажені пасажирським і вантажним транспортом, а промислові й шахтні рейкові колії цілодобово використовуються у виробничому процесі, обстеження можна проводити лише на трамвайних коліях під час зупинок руху трамваїв у нічний час. Результати цих вимірювань на трамвайних коліях можуть допомогти зрозуміти термін служби рейкових колій і можуть бути використані на магістральних, промислових і шахтних залізничних коліях.

Результати. Проаналізована зміна середніх значень обраних геометричних параметрів колії з урахуванням типових погодних умов. На основі проведених вимірювань і отриманих результатів встановлено очевидний зв'язок між оціненими результатами вимірювань геометричних параметрів колії та зміною погодних умов.

Наукова новизна. Знаходження зв'язків між змінами значень геометричних параметрів колії та погодними умовами на базі оцінки результатів вимірювань її характеристик, що виконуються в середньому кожен третій місяць.

Практична значимість. У подальшому отримані результати можуть стати вихідними даними для визначення терміну служби системи баластної верхньої будови колії у випадку трамвайних, магістральних, промислових і шахтних залізничних колій.

Ключові слова: *рейковий транспорт, знос, баластна колія, транспортне навантаження, ширина колії*