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INVESTIGATION OF GEOMETRICAL DETERIORATION OF TRAMWAY TRACKS

Purpose. The authors' aim is to demonstrate their results of analysis of deterioration of tramway tracks' geometry. **Methodology.** This article is a start of a PhD research. At first, the superstructure systems and the used instrument were summarized, after that the examination of running track, tramway stops, crossings and turnouts. **Findings.** The authors examined separately the running track, tramway stops, level crossings and turnouts. In case of examination of running track, we evaluated the measurement results according to two methods. To clarify the superstructure systems' deterioration factor the authors had to do further measurements on other tramway lines too. **Originality.** The fulfilled analysis is the first step to the complex method that can consider and determine the optimisation of life-cycle costs of tramway superstructures. For this goal a lot of parameters, factors have to be taken into consideration in the future. There are available methods and models for different civil engineering areas, e.g. there is very complex methodology related to road pavements, but there is no special one related neither to railway tracks, nor tramway tracks. **Practical value.** The authors tried to construct a calculation and evaluation method that can assess the examined 6 different tramway superstructure types on the tramway line No. 1 in Hungarian capital (Budapest). It is a very new reconstructed tramway line that is the second longest one in Budapest. The authors showed which type of superstructure system is the «best» and the «worst» based on own made measurements and calculation-evaluation methods. The next aim of the authors is to start a PhD research in the Multidisciplinary Doctoral School at Szechenyi Istvan University (Győr, Hungary) with the continuation of this topic.

Keywords: superstructure systems; deterioration; geometrical analysis; tramway; assessment

Purpose

The aim of this paper is to demonstrate research results related to analysis of deterioration of tramway tracks' geometry. This paper deals with the 7 different superstructure systems in Hungary, and with these deteriorations in a chosen tramway line.

This research is our first step to diagnose the several superstructure systems' life cycle cost managements.

This paper is based on the MSc thesis of V. Jóvér (one of the authors of this article) [5], the defense was in 2020 February. She would like to start her PhD study in 2020 September with the topic of «Optimisation of life-cycle costs of tramway superstructures».

The authors made a short literature review related to life time engineering and life cycle cost calculation [4], tramway tracks' superstructure types [3], calculation of vertical deformation of railway tracks [2, 8], as well as turnouts [6, 10, 11, 12, 13, 14, 15] and crossings [1]. In the following the author summarize the relevant point from them.

Kurhan [8] analysed the processes of emergence and development of irregularities in the area of unequal vertical elasticity of railway track using mathematical modelling. He adopted model consists of a wheel set moving on inertia-free beam and resting on individual supports. It is described by Lagrange differential equations. The work introduced the hypothesis that the level of permanent strain is distributed in proportion to the dynamic deflection derivative. In [2] Kurhan investigated an entropy based deformation (accumulative) calculation method for railway tracks. These are very important in the area of tramway tracks, too, mainly for ballasted types tramway tracks, too, mainly for ballasted types.

In tramway tracks there are a lot of special turnouts. The literature [6, 10, 11, 12, 13, 14, 15] investigated the turnouts, mainly the common crossings

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and the frogs, as well as frog noses. The research team applied mainly dynamic measurements techniques that are important in case of tramway tracks, too. They dealt with the material, geometry, traffic loading, etc. of special elements in turnouts. In Hungary according to tramway tracks, turnouts constructed with Vignol and grooved rail profiles are applied [7].

In case the level crossings are investigated, there is an interested article [1]. In [1] the authors performed statistical analysis showed a steady trend of growth of inequalities in the area of the railway crossings. Generally, the level of inequalities in the vertical plane increases in 1.3-3.2 times and in 1.2-2.0 times in the horizontal plane (compared with areas that are outside crossing). During the deflection lines of action in the area of railroad crossing concrete slabs work as ribs that limit deflections of rail-tie grating. When placing the wheels of the bogie before (or after) and within crossing the calculated modulus of elasticity under the rail base, brought to the point of wheels contact can vary up to 3 times.

Gáspár et al. [4] introduced the main factors related to lifetime of different transport infrastructure elements (road pavements, railway tracks and bridges). There are many factors that influence the real and prognosed lifetime, e.g. plans, traffic types and modes, construction method, materials, maintenance, environment, etc.

Methodology

The invention of electricity has taken a huge turn in development of public transport. The first Hungarian tramway was opened in Budapest (capital of Hungary) in 1887, it was only one kilometer long. Since then the public transport organizations which build the tramways are constantly developing.

In case of tramways, 7 different superstructure systems (types) can be differentiated in Hungary. They are chosen for each project, depending on factors such as the installation site, the track closure and the geometric characteristics. The 7 types are the following:

- ballasted track (Fig. 1-2);
- concreted ballasted track (Fig. 3-4);
- concrete slab track (Fig. 5-6);
- ESCRB I. track system track (ESCRB means elastically supported continuous rail bedding system, in Hungarian RAFS abbreviation is applied) (Fig. 7-8);
- ESCRB II. track system (Fig. 9-10);
- ESCRB III. track system (Fig. 11-12);
- «large slab» («big panel») superstructure (Fig. 13-14) [7].

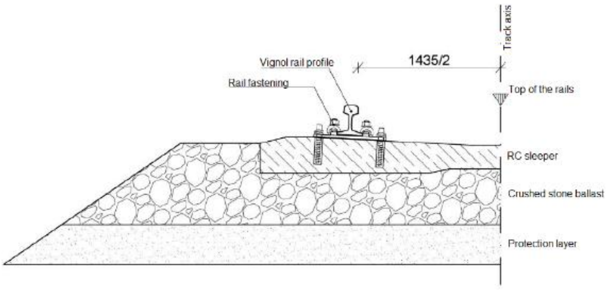

Fig. 1. Cross-section of ballasted track [7]

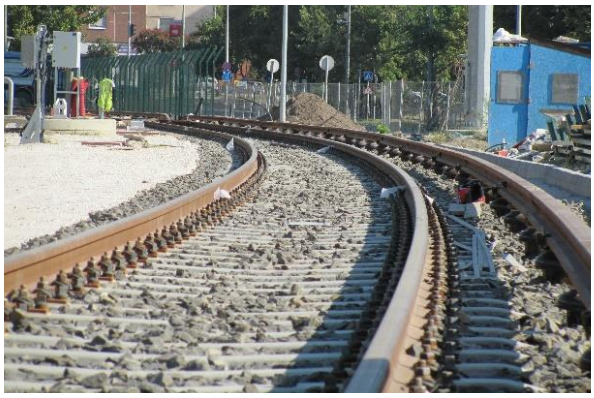

Fig. 2. Ballasted track superstructure

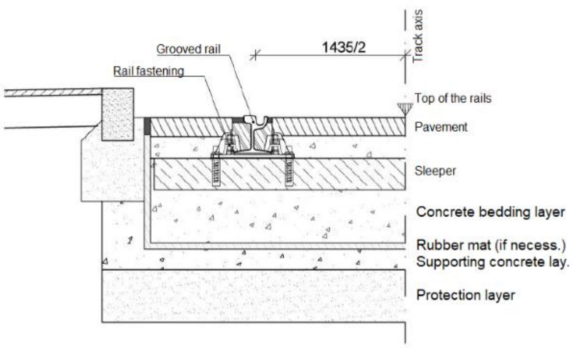

Fig. 3. Cross-section of concreted ballasted track [7]

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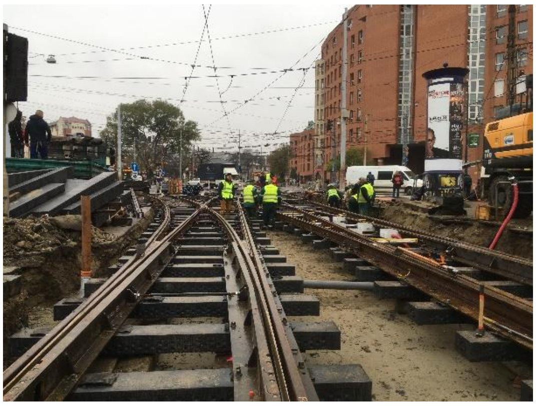

Fig. 4. Concreted ballasted track superstructure during construction

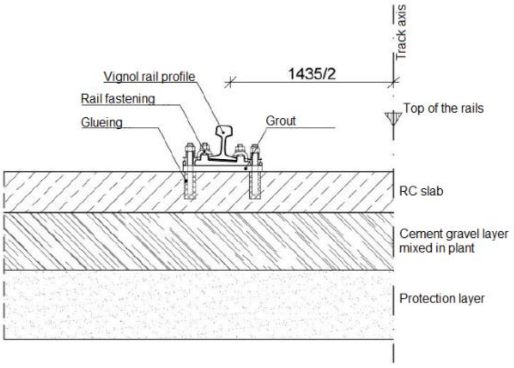

Fig. 5. Cross-section of concrete slab track [7]

Fig. 6. Concrete slab track during construction

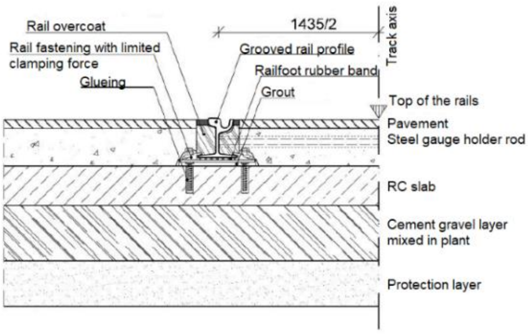

Fig. 7. Cross-section of ESCRB I. track system [7]

Fig. 8. ESCRB I. track system during construction

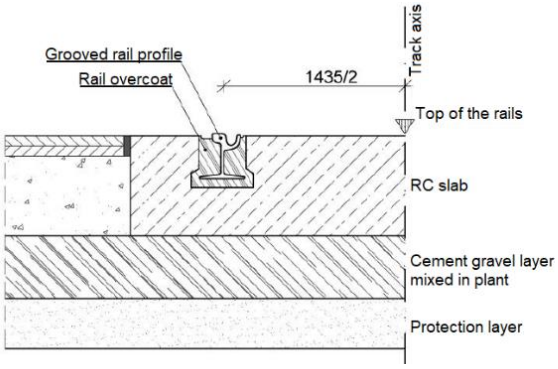

Fig. 9. ESCRB II. track system [7]

Fig. 10. ESCRB II. track system during construction

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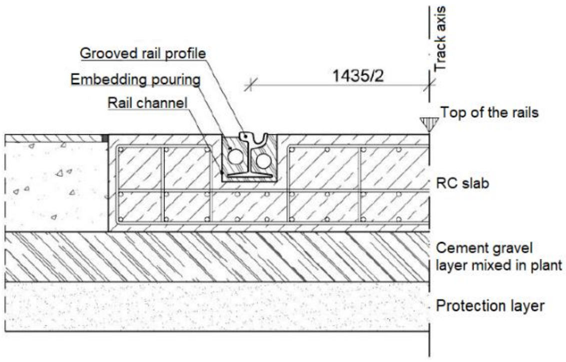

Fig. 11. Cross-section of ESCRB III. track system [7]

Fig. 12. ESCRB III. track system

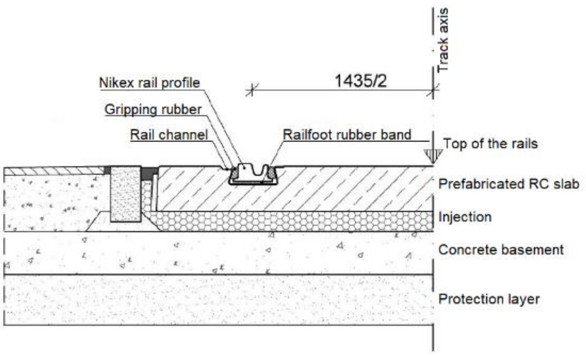

Fig. 13. Cross-section of «large slab» («big panel») superstructure [7]

Fig. 14. «Large slab» superstructure

The aim of the authors' research was to investigate all the varieties (types) of tramway superstructure systems in Hungary. The most important task during choosing the right tramway line (or track) for the analysis was equal allowable load and the more varieties of superstructure systems at the same tramway. The authors selected the tramway line No. 1 in the Hungarian capital (Budapest) where six different types of tramway superstructure systems were able to be investigated.

The tramway line No. 1 in Budapest was built for several years, applied the most modern technical upgrades. The tramway was completed in 2019 and became the longest tramway line in Budapest. It is 18.2 kilometers long and contains 32 tramway stops, 35 crossings and 22 turnouts.

Tramway tracks' geometry measurements

Geometrical measurements were executed in the right track at nights, between 0:30 AM and 3:30 AM with TrackScan 4.01 instrument (see Fig. 15). This instrument can measure the following parameters simultaneously:

- track gauge;
- flange gauge;
- superelevation;
- direction;
- settlement;
- length of the railway section;
- twist [9].

The authors were able to evaluate the measurement data with TrackScan Desktop software where they applied the so called «B – maintenance limit» category in accordance with Hungarian regulations related to tramway tracks.

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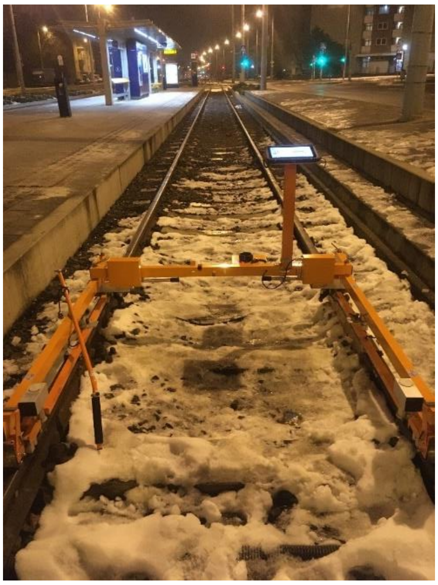

Fig. 15. TrackScan 4.01 Instrument

Examination of deterioration of superstructure systems

To evaluate the measurement data, a subjective scoring system was made with the following parameters:

- the type of the default;
- the length of the default;
- geometric characteristics;
- the length of superstructures;
- speed of trams;
- load of trams;
- unit costs;
- life-span.

Connecting to these parameters the authors have assigned so called «weights», from which they were able to calculate the «deterioration factor». The higher the deterioration factor of a superstructure system, the more intense, faster the track geometric deterioration.

Examination of running track

The evaluation of measurement data of running track manifested 140 defaults, they were the followings (Fig. 16):

- broadening of track gauge;
- narrowing of track gauge;
- twist;
- superelevation.

After the evaluation the authors had to check the length of defaults. In many cases, the appearance of local defaults was caused by contaminated of grooved rail profiles.

In case of superelevation defaults two cases had to be considered:

• the final tramway geometry plans do not contain superelevation values but the measurement results exceed the «B – maintenance limit» values, or

• the final tramway geometry plans contain superelevation values but the measurement results also exceed the «B – maintenance limit» values.

The authors assessed the measurement results of running track according to two methods detailed in the «Findings» Chapter.

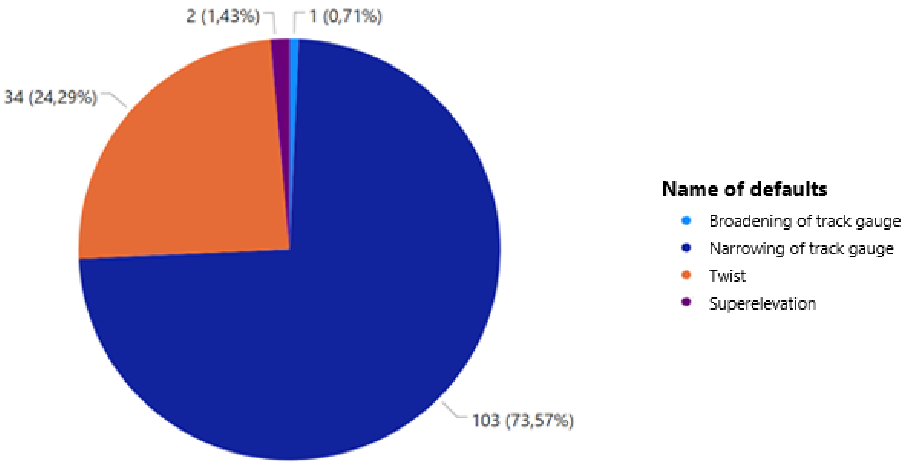

Fig. 16. The occurrence of defaults, as measured by «B – maintenance limit»

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Наука та прогрес транспорту. Вісник Дніпропетровського національного університету залізничного транспорту, 2020, № 2 (86)

Findings

In this Chapter the authors summarize the results of the investigation related to the different calculation and evaluation methods.

Evaluation of measurement results – case #1

According to the case #1 the authors applied the following parameters:

- the type of the default;
- geometric characteristics;
- the length of superstructures;
- speed of trams;
- load of trams;
- unit costs;
- life-span.

In this case instead of the length of the default the total length of each superstructure system to the number of defaults they contain was considered and compared.

Using the subjective scoring system, the results are shown in Fig. 17. Figure 17 shows the percentage of the deterioration factors of the various superstructure systems. The benchmark is based on the most common superstructure system on the tramway line which is grooved rail profile, ESCRB on RC slab, with asphalt pavement. Its deterioration factor is 100% (see Fig. 17). It seems the deterioration of the superstructure type with Vignol 48 rail profile, crushed stone ballast, and concrete sleepers is outstanding. The type of the defaults is mostly narrowing of the track gauge.

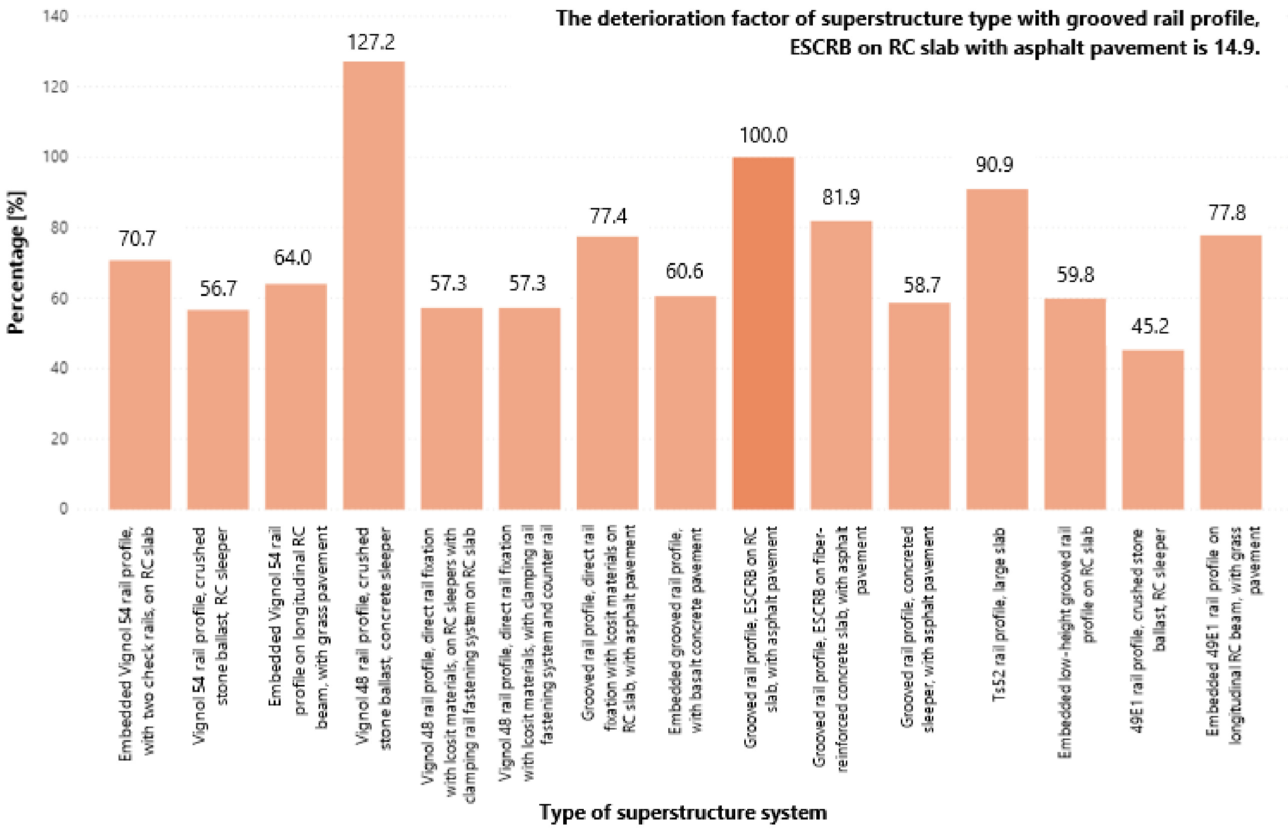

Fig. 17. The percentage of deterioration factors relative to each other – first version

Evaluation of measurement results – case #2

According to the case #2 the authors applied the parameters below:

- the type of the default;
- the length of the default;
- geometric characteristics;
- speed of trams;
- load of trams;
- unit costs;
- life-span.

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In this case instead of the length of the superstructures the authors considered the length of the defaults as follows:

$$\frac{maximum\ default\ value\ \times length\ of\ the\ default}{total\ length\ of\ the\ given\ superstructure\ system}$$

The analysis of the measurement results shows that as in case #1, the deterioration of the superstructure type constructed with Vignol 48 rail profile, crushed stone ballast, and concrete sleepers has the highest value – 14% higher than the benchmark grooved rail profile, ESCRB on RC slab, with asphalt pavement superstructure system (Fig. 18).

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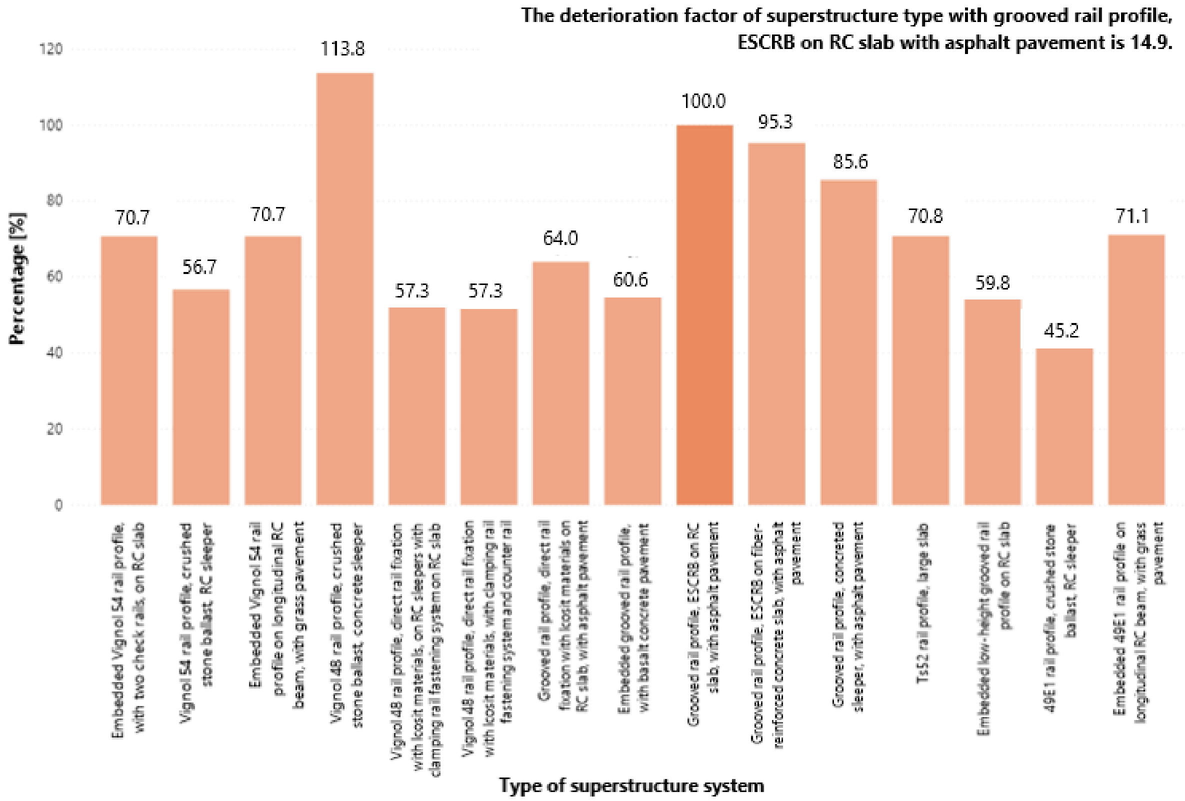

Fig. 18. The percentage of deterioration factors relative to each other – second version

Comparing the results from cases #1 and #2, it is noticeable that by modifying the parameters, the values of deterioration factors for each superstructure system have also been modified (Fig. 19). This can be explained by the fact that these superstructure system types are only found in small lengths over the entire tramway line, but many defaults have occurred since they were constructed.

It is also important to investigate the deterioration of different types of superstructure systems as a function of elapsed time. The authors' measurements indicate a specific date and there isn't other measurement date since the construction, in this way the relationship between deterioration of superstructure system and elapsed time since construction is not able to be assessed, yet. The authors assume that in practice this relation would produce an exponential function that accelerates in time – but they have to prove this by further measurements, calculations, investigations and evaluations.

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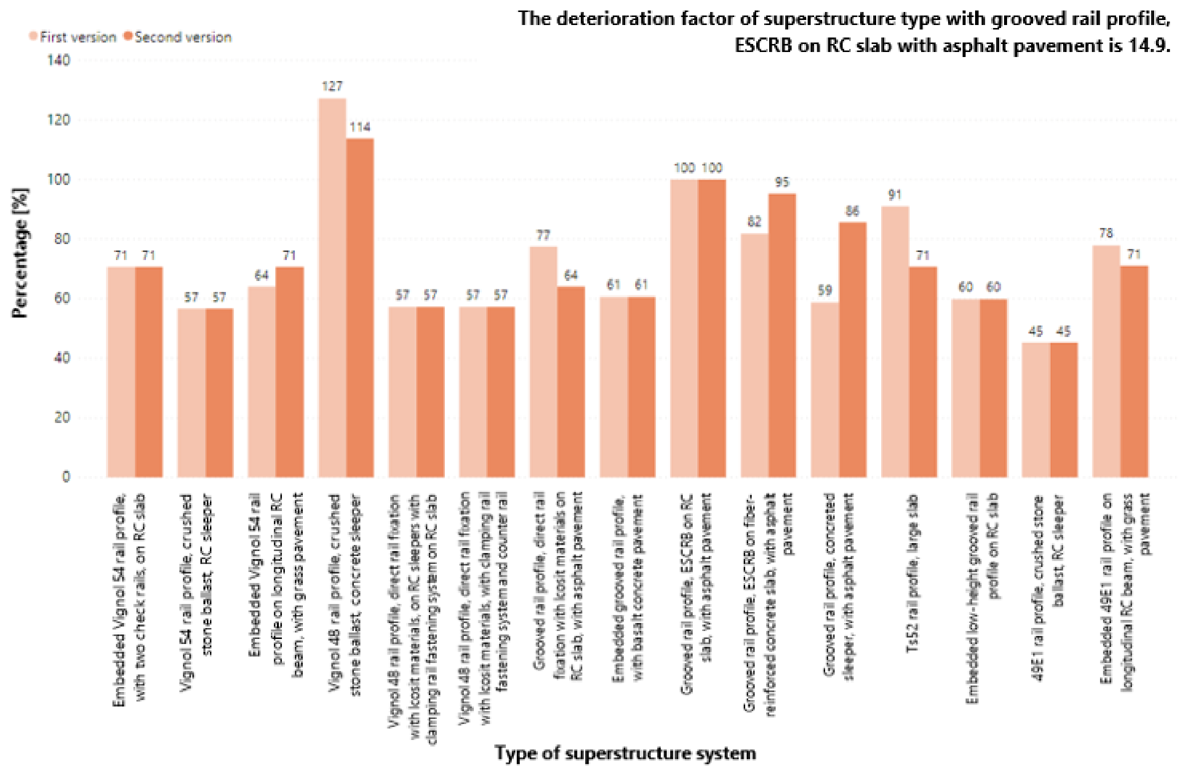

Fig. 19. The percentage of deterioration factors relative to each other – first and second version

Evaluation of superelevation values

In case of superelevation defaults two cases had to be examined:

- the final tramway geometry plans do not contain superelevation values but the measurement results exceed the «B – maintenance limit» values, or
- the final tramway geometry plans contain superelevation values but the measurement results also exceed the «B – maintenance limit» values.

Based on the analysis of the results the authors noticed that superelevation defaults appeared at considerable lengths where the values should be 0 mm.

The ratio of the length of the given superstructure system to the superelevation defaults on that is also evaluated. This value is compared to the average of the deterioration factors (average of cases #1 and #2), it should be noticed that the deterioration of the superstructure type with grooved rail profile, direct rail fixation with Icosit materials on RC slab, with asphalt pavement is outstanding (Fig. 20).

Examination of tramway stops

Related to the evaluation of tramway stops the authors used the following parameters:

- geometric characteristics;
- speed of trams;
- load of trams;
- unit costs;
- life-span.

Furthermore, the cumulate lengths of platforms with the same superstructure system were examined and they were compared to the cumulate number of defaults they contain.

Using the subjective scoring system, it should be noticed that the deterioration of the superstructure type with Vignol 48 rail profile, crushed stone ballast, as well as concrete sleepers is outstanding – as in the case of running track (Fig. 21). The benchmark is based on the most common superstructure system on the tramway line which is grooved rail profile, ESCRB on RC slab, with asphalt pavement. Its deterioration factor is 100%.

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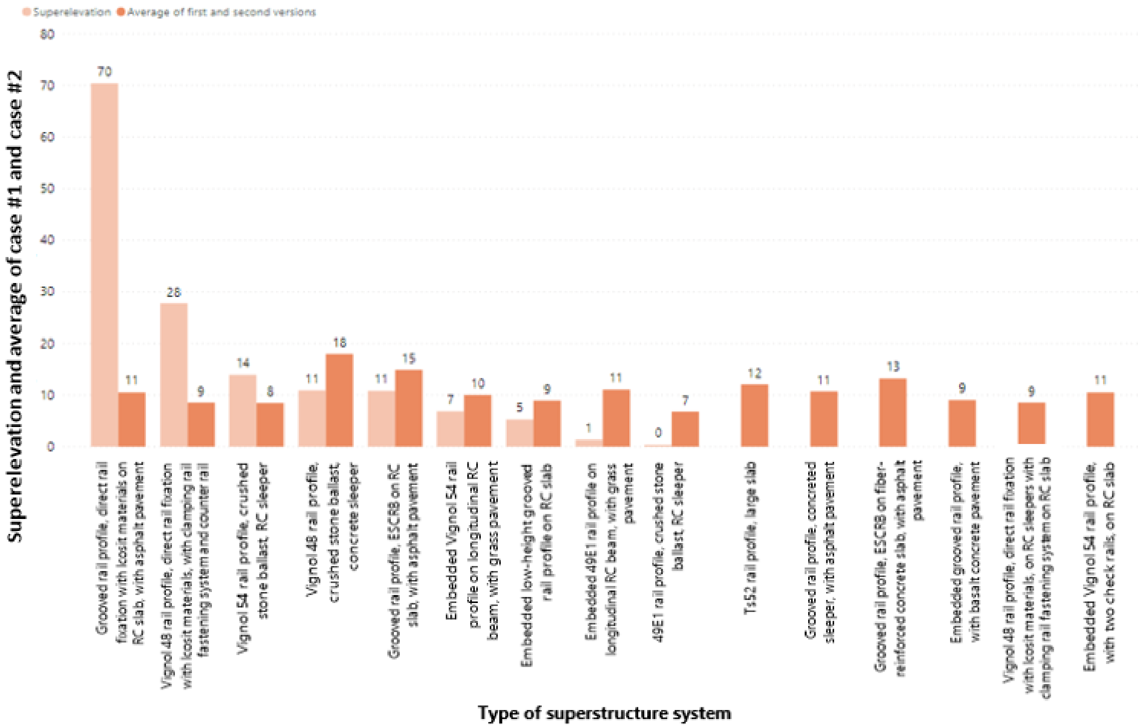

Fig. 20. The joint analysis of length of superelevation defaults and average of first and second versions' deterioration factors

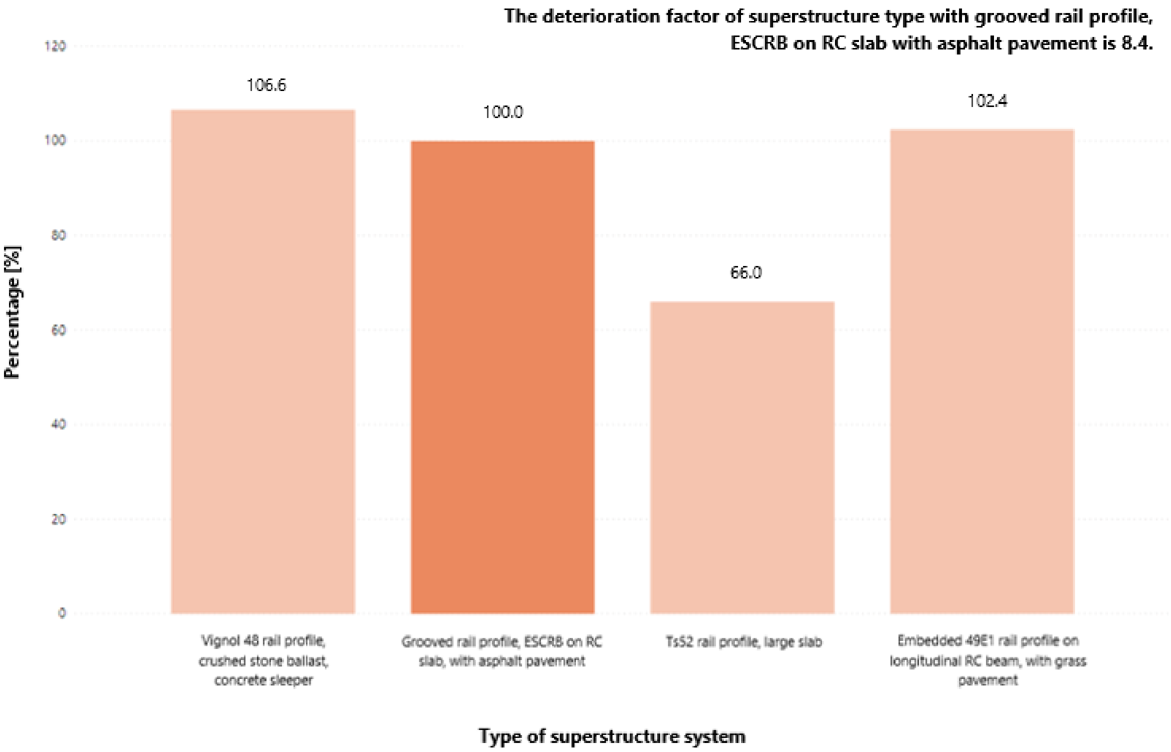

Fig. 21. The percentage of deterioration factors relative to each other at tramway stops

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Examination of level crossings

Related to the evaluation of level crossing the authors used the following parameters:

- geometric characteristics;
- speed of trams;
- load of trams;
- unit costs;
- life-span.

Furthermore, the authors examined the cumulate lengths of crossings with the same superstructure system and then compared it to the cumulate number of defaults they contain.

The results show that the deterioration of the grooved rail profile, ESCRB on RC slab, with asphalt pavement superstructure system is outstanding (Fig. 22.). In this case, the benchmark is the grooved rail profile, ESCRB on RC slab, with basalt concrete pavement superstructure system.

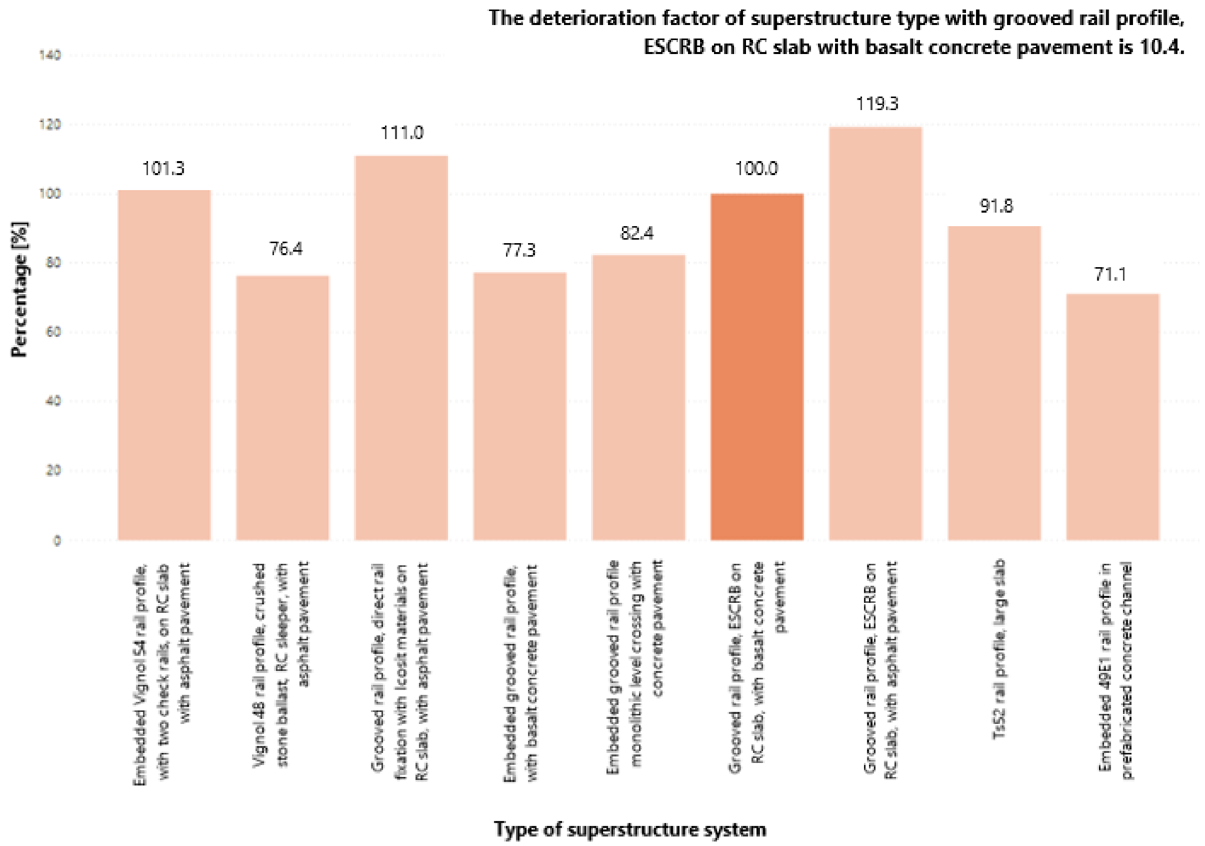

Fig. 22. The percentage of deterioration factors relative to each other – in level crossings

Examination of turnouts

The tramway line No. 1 in Budapest contains 22 pieces of turnouts in the right track, with both grooved and Vignol rail profiles.

Generally, they are in good condition, only two of them has superelevation defaults. In the first case, the Phoenix 50/50 type turnout has 13.7 mm superelevation default value on average. In the second case, the B48 100/100e type turnout has 10.5 mm superelevation default value on average.

Originality and practical value

The authors investigated the deterioration of tramway track geometry based on example of tramway line No. 1 in Hungarian capital, Budapest. This tramway line was reconstructed in the past few years and it contains 6 different superstructure types from the 7, that can be applied in Hungary [7].

Because of this tramway line works with the highest tram traffic in Budapest, as well as the superstructures are relatively new, geometric meas-

doi: https://doi.org/10.15802/stp2020/204152

urements were executed on the whole line in November and December 2019. The measurement instrument was a Trackscan apparatus [9]. Based on the measurements the authors made calculations and assessments according to two cases (#1 and #2). They considered not only the running tracks, but the tramway stops, level crossings, as well as the turnouts, too.

In the analyses several parameters were taken into consideration, e.g. the type of the default, geometric characteristics, the length of superstructures, speed of trams, load of trams, unit costs, and lifespan. The authors calculated deterioration factors according to the previous parameters and made evaluations where they compared the different tramway superstructure types in running tracks, tramway stops, level crossings, turnouts.

The authors determined – according to their measurements and calculations – that the 49E1 rail profile, crushed stone ballast, RC sleeper type superstructure is almost the 'best' and the Vignol 48 &rail profile, crushed stone ballast, and concrete sleepers type superstructure is the «worst» for construction tramway tracks using a subjective scoring system.

The observation of geometrical deterioration of tramway tracks' is a very important part of the railway tracks' maintenance procedure. Because of it, the knowledge has to be improved and as many methods as possible has to be applied to learn more about tramway's deterioration.

To clarify the superstructure systems' deterioration factor the authors have to execute further measurements on other tramway lines, too. They can be Hungarian tramway lines, as well as examples from abroad.

The next aim is to sentence research plan related to one of the authors (Vivien Jóvér), and start her PhD research at Széchenyi István University (Hungary). Hopefully, she can submit her dissertation in 2024 or 2025.

Acknowledgements

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LIST OF REFERENCE LINKS

1. Курган М. Б., Курган Д. М., Лужицький О. Ф. Дослідження нерівностей колії в межах залізничних переїздів. *Наука та прогрес транспорту*. 2015. № 5 (59). С. 84–96. DOI: https://doi.org/10.15802/stp2015/55341
2. Курган Д. М. Моделювання накопичення деформацій залізничної колії на основі ентропії системи. *Наука та прогрес транспорту*. 2015. № 4 (58). С. 99–109. DOI: https://doi.org/10.15802/STP2015/49215
3. Case studies in railway construction. Modern tramway superstructures. URL: http://www.sze.hu/~fischersz/Education/Case%20studies%20in%20railway%20construction/CSRC_Topic%2006_Modern%20tramway%20superstructures.pdf (date of access 14.01.2020).
4. Gáspár L., Horvát F., Lublóy L. *Közlekedési létesítmények élettartama*. Universitas-Győr Nonprofit Kft. Győr, 2011, 324 p.
5. Jóvér V. Közúti vasúti felépítmény-szerkezetek komplex elemzése. MSc thesis. Széchenyi István Egyetem. Győr, 2019. 82 p. DOI: https://doi.org/10.13140/RG.2.2.16467.53284
6. Kovalchuk V., Sysyn M., Gerber U., Nabochenko O., Zarour J., Dehne S. Experimental investigation of the influence of train velocity and travel direction on the dynamic behavior of stiff common crossings. *Facta Universitatis. Series : Architecture and Civil Engineering*. 2019. № 3 (17). P. 345–356. DOI: https://doi.org/10.22190/FUME190514042K
7. Közúti vasúti infrastruktúra tervezési irányelvek. URL: https://static.bkv.hu/ftp/ftp/fajlok/sarga_konyv/15.pdf (date of access 14.01.2020).
8. Kurhan D. M. Modeling of development vertical deformation of railway track. *Наука та прогрес транспорту*. 2016. № 1 (61). P. 100–108. DOI: https://doi.org/10.15802/stp2016/61003
9. Metalelektro Railway Diagnostic. Track Geometry Measurement. URL: https://www.metalelektro.eu/track-geometry (date of access 14.01.2020).
10. Sysyn M., Nabochenko O., Gerber U., Kovalchuk V., Petrenko O. Common crossing condition monitoring with on board inertial measurements. *Acta Polytechnica*. 2019. Vol 4. Iss. 59. P. 423–434. DOI: https://doi.org/10.14311/AP.2019.59.0423

doi: https://doi.org/10.15802/stp2020/204152

11. Sysyn M., Gerber U., Nabochenko O., Kovalchuk V. Common crossing fault prediction with track based inertial measurements: statistical vs. mechanical approach. *Pollack Periodica*. 2019. Vol. 2. Iss. 14. P. 15–26. DOI: https://doi.org/10.1556/606.2019.14.2.2
12. Sysyn M., Kluge F., Gruen D., Kovalchuk V., Nabochenko O. Experimental analysis of rail contact fatigue damage on frog rail of fixed common crossing 1:12. *Journal of Failure Analysis and Prevention*. 2019. Vol. 21. Iss. 19. P. 1077–1092. DOI: https://doi.org/10.1007/s11668-019-00696-w
13. Sysyn M. Improvement of inspection system for common crossings by track side monitoring and prognostics. *Structural Monitoring and Maintenance*. 2019. Vol. 3. Iss. 6. P. 219–235. DOI: https://doi.org/10.12989/smm.2019.6.3.219
14. Sysyn M., Gerber U., Nabochenko U., Li Y., Kovalchuk V. Indicators for common crossing structural health monitoring with track-side inertial measurements. *Acta Polytechnica*. 2019. Vol. 2. Iss. 59. P. 170–181. DOI: https://doi.org/10.14311/AP.2019.59.0170
15. Sysyn M., Gerber U., Kluge F., Nabochenko O., Kovalchuk U. Turnout remaining useful life prognosis by means of on-board inertial measurements on operational trains. *International Journal of Rail Transportation*. 2019. P. 1–23. DOI: https://doi.org/10.1080/23248378.2019.1685918

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ДОСЛІДЖЕННЯ ПОГІРШЕННЯ ГЕОМЕТРІЇ ТРАМВАЙНИХ КОЛІЙ

Мета. Основною метою статті є демонстрація результатів аналізу погіршення геометрії трамвайних колій. **Методика.** Ця стаття є часткою дослідження в рамках кандидатської дисертації. Спочатку були узагальнені системи верхньої будови колії та інструменти, використані під час роботи, після чого була проведена перевірка колії, зупинок трамвая, перетинів колій і стрілочних переводів. **Результати.** Автори провели дослідження окремої трамвайної колії, зупинок трамвая, переїздів та стрілочних переводів. Під час дослідження колії оцінювали результати вимірювань відповідно до двох методик. Для визначення фактора зносу систем верхньої будови колії провели додаткові вимірювання також на інших трамвайних лініях. **Наукова новизна.** Виконаний аналіз є першим кроком складної методики, яку використовують під час розгляду й оптимізації витрат життєвого циклу верхньої будови трамвайної колії. Для досягнення цієї мети існує багато параметрів, факторів, які необхідно взяти до уваги в майбутньому. Наявні методи й моделі, які використовують у різних галузях цивільного будівництва, наприклад, дуже складна методика, пов’язана з дорожнім покриттям; але не існує спеціальної методики, що стосується залізничних або трамвайних колій. **Практична значимість.** Автори спробували розробити методику розрахунку й оцінки, за допомогою якої можна оцінити 6 різних типів верхньої будови трамвайної колії на лінії № 1 в столиці Угорщини (Будапешт). Це найновіша реконструйована трамвайна лінія, друга за довжиною в Будапешті. Визначили, який тип системи верхньої будови колії є «найкращим» і «найгіршим» на основі власних вимірювань і методів розрахунку та оцінки. Проведене дослідження авторів ляже в основу написання кандидатської дисертації в багатопрофільній аспірантурі при Університеті Іштвана Сечені (Дьєр, Угорщина).

Ключові слова: системи верхньої будови колії; погіршення; геометричний аналіз; трамвайні лінії; оцінка

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ИССЛЕДОВАНИЕ УХУДШЕНИЯ ГЕОМЕТРИИ ТРАМВАЙНЫХ ПУТЕЙ

Цель. Основной целью статьи является демонстрация результатов анализа ухудшения геометрии трамвайных путей. **Методика.** Данная статья является частью исследования в рамках кандидатской диссертации. Сначала были обобщены системы верхнего строения пути и инструменты, использованные во время работы, после чего была проведена проверка пути, остановок трамвая, пересечений путей и стрелочных переводов. **Результаты.** Авторы провели исследование отдельного трамвайного пути, остановок трамвая, переездов и стрелочных переводов. Во время исследования пути оценивали результаты измерений в соответствии с двумя методиками. Для определения фактора износа систем верхнего строения пути провели дополнительные измерения также на других трамвайных линиях. **Научная новизна.** Выполненный анализ является первым шагом сложной методики, которую используют при рассмотрении и оптимизации затрат жизненного цикла верхнего строения трамвайного пути. Для достижения этой цели существует много параметров, факторов, которые необходимо принять во внимание в будущем. Существуют методы и модели, которые используют в различных областях гражданского строительства, например, очень сложная методика, связанная с дорожными покрытиями; но не существует специальной методики, касающейся железнодорожных или трамвайных путей. **Практическая значимость.** Авторы попытались разработать методику расчета и оценки, с помощью которой можно оценить 6 различных типов верхнего строения трамвайного пути на линии № 1 в столице Венгрии (Будапешт). Это самая новая реконструированная трамвайная линия, вторая по длине в Будапеште. Определили, какой тип системы верхнего строения пути является «лучшим» и «худшим» на основании собственных измерений и методов расчета и оценки. Проведенное исследование ляжет в основу написания кандидатской диссертации в многопрофильной аспирантуре при Университете Иштвана Сечени (Дьер, Венгрия).

Ключевые слова: системы верхнего строения пути; ухудшение; геометрический анализ; трамвайные линии; оценка

REFERENCES

1. Kurhan, M. B., Kurhan, D. M., & Luzhytskyi, O. F. (2015). Inequalities research of the track at the railroad crossings. *Science and Transport Progress, 5*(59), 84-96. DOI: https://doi.org/10.15802/stp2015/55341 (in Ukrainian)
2. Kurhan, D. M. (2015). Accumulated deformation modeling of permanent way based on entropy system. *Science and Transport Progress, 4*(58), 99-109. DOI: https://doi.org/10.15802/stp2015/49215 (in Ukrainian)
3. Case studies in railway construction. Modern tramway superstructures. Retrieved from http://www.sze.hu/~fischersz/Education/Case%20studies%20in%20railway%20construction/CSRC_Topic%2006_Modern%20tramway%20superstructures.pdf (in English)
4. Jóvér, V. (2019). *Közúti vasúti felépítmény-szerkezetek komplex elemzése. MSc thesis*. Széchenyi István Egyetem. Győr. DOI: https://doi.org/10.13140/RG.2.2.16467.53284 (in Hungarian)
5. Kovalchuk, V., Sysyn, M., Gerber, U., Nabochenko, O., Zarour, J., & Dehne, S. (2019). Experimental investigation of the influence of train velocity and travel direction on the dynamic behavior of stiff common crossings. *Facta Universitatis. Series: Mechanical Engineering, 17*(3), 345-356. DOI: https://doi.org/10.22190/FUME190514042K (in English)
6. Gáspár, L., Horvát, F., & Lublóy, L. (2011). *Közlekedési létesítmények élettartama*. Universitas-Győr Nonprofit Kft. Győr. (in Hungarian)
7. Közúti vasúti infrastruktúra tervezési irányelvek. Retrieved from https://static.bkv.hu/ftp/ftp/fajlok/sarga_konyv/15.pdf (in Hungarian)
8. Kurhan, D. M. (2016). Modeling of development vertical deformation of railway track. *Science and Transport Progress*, 1(61), 100-108. DOI: https://doi.org/10.15802/stp2016/61003 (in English)
9. Metalelektro Railway Diagnostic. Track Geometry Measurement. Retrieved from https://www.metalelektro.eu/track-geometry (in English)
10. Sysyn, M., Nabochenko, O., Gerber, U., Kovalchuk, V., & Petrenko, O. (2019). Common crossing condition monitoring with on board inertial measurements. *Acta Polytechnica, 59*(4), 423-434. DOI: https://doi.org/10.14311/ap.2019.59.0423 (in English)

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11. Sysyn, M., Gerber, U., Nabochenko, O., & Kovalchuk, V. (2019). Common crossing fault prediction with track based inertial measurements: statistical vs. mechanical approach. *Pollack Periodica, 14*(2), 15-26. DOI: https://doi.org/10.1556/606.2019.14.2.2 (in English)
12. Sysyn, M., Kluge, F., Gruen, D., Kovalchuk, V., & Nabochenko, O. (2019). Experimental Analysis of Rail Contact Fatigue Damage on Frog Rail of Fixed Common Crossing 1:12. *Journal of Failure Analysis and Prevention*, *19*(4), 1077–1092. DOI: https://doi.org/10.1007/s11668-019-00696-w (in English)
13. Sysyn, M. (2019). Improvement of inspection system for common crossings by track side monitoring and prognostics. *Structural Monitoring and Maintenance*, *3*(6), 219-235. DOI: https://doi.org/10.12989/smm.2019.6.3.219 (in English)
14. Sysyn, M., Gerber, U., Nabochenko, U., Li, Y., & Kovalchuk, V. (2019). Indicators for common crossing structural health monitoring with track-side inertial measurements. *Acta Polytechnica*, *59*(2), 170-181. DOI: https://doi.org/10.14311/AP.2019.59.0170 (in English)
15. Sysyn, M., Gerber, U., Kluge, F., Nabochenko, O., & Kovalchuk, U. (2019). Turnout remaining useful life prognosis by means of on-board inertial measurements on operational trains. *International Journal of Rail Transportation*, 1-23. DOI: https://doi.org/10.1080/23248378.2019.1685918 (in English)

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