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Oleksandr Aharkov[1*], Volodymyr Tverdomed [2]

[1]Assistant professor, Theoretical and Applied Mechanics Department, State University of Infrastructure and Technologies, 9, Kyrylivska str., Kyiv, 04071, Ukraine, ORCID: https://orcid.org/0000-0001-8250-6280
[2]Assistant professor, Railway Track and Track Facilities Department, State University of Infrastructure and Technologies, 9, Kyrylivska str., Kyiv, 04071, Ukraine, ORCID: https://orcid.org/0000-0002-0695-1304

***Corresponding author:** agarkov_ov@gsuite.duit.edu.ua

Comparative analysis of damages and defects in rails of different railway transport systems

This article provides an analysis of the accumulation of detected damages and defects in the rails of two transportation systems - urban (metro) and mainline railway transport. Summarizing the analysis conducted, it should be noted that defects according to figures 10 and 11 are more often encountered on the tracks of the Kyiv Metro. At the same time, defects according to figure 27 are more often encountered on the tracks of the mainline railway transport, and it is also worth noting a wider range of defects, the share of which does not exceed 5%. According to the authors, this is related to the peculiarities of the conditions for operating transportation systems, particularly the load on the axle of the moving equipment, the movement characteristics, and other operational parameters. In order to make more accurate conclusions, it is necessary to perform a number of works using mathematical modeling methods to take into account the influence of individual parameters on the accumulation of defects and damages in rails.

Keywords: *rolling stock, transport system, wheel pair, rail, railway track, defect, damage, fatigue, cracking.*

Introduction. One of the most common types of transportation in every country in the world is rail transport. This type of transport provides passenger transportation in large cities, intercity and international connections. A significant share of freight transportation falls precisely on rail transport [1]. To ensure the transportation process, the railway transport system must provide uninterrupted and safe train traffic. The railway infrastructure is a significant part of the railway transport system, and the organization of a safe and timely transportation process depends largely on its technical condition [2, 3].

The interaction of the rolling stock and the railway track (the weight of the wagon, the speed of movement, the intensity of the applied loads), the influence of natural factors - air temperature (frost causes cracks in the railway track, heat - track buckling, primarily in continuous welded rail), precipitation (rain, snow melting lead to washouts or moistening of the ballast layer), and human factors (untimely or poor elimination of malfunctions that arose during operation) have a significant impact on the speed of appearance of damage and defects in the elements of the railway track and rolling stock.

To ensure the safety of trains traveling at established speeds, periodic monitoring of the condition of railway infrastructure is carried out. One of the components of the system for ensuring the trouble-free operation of railway infrastructure is the technical diagnostics of rails using a complex of non-destructive testing methods. The management of the lifecycle of rails plays an important role in optimizing the overall costs of railway infrastructure and includes the optimal selection of rail types, rail diagnostics, and maintenance. This article analyzes the accumulation of detected damages and defects in the rails of two transportation systems - urban (metro) and mainline railways.

Analysis of recent research and problem statement. During operation, the condition of rails gradually deteriorates and their load-bearing capacity decreases, which leads to the need for individual or overall replacement of rails due to defects formation in them.

Management of damages and defects in rails during rolling contact is of crucial importance for transport safety worldwide, as uncontrolled development of these defects can cause railway accidents, including derailments.

A large number of scientific papers and research projects have been published that consider railway defects from the aspects of metallurgy, testing methods, railway infrastructure, and transport means [6, 7, 8].

The article [9] provides a critical analysis of the classification of rail defects. The general system of classification of defects in the main transportation system based on their localization, causes, and external appearance was considered. Special attention was paid to the correspondence of the names and code numbers of rail defects used in EN standards and UIC recommendations. In addition, recommendations were presented for improving the coding system based on experience with defects in the Serbian main transportation system.

The authors proposed a database of rail defects, which should consist of defect photographs, information about the localization of defects, methods of detecting and classifying rail defects. Fragments of information contained in the database should be used for planning maintenance activities. To ensure effective management of rail defects, it is necessary to consolidate data on the design of each structural element of the track superstructure. The collected data on rail defects and the conditions of maintenance of the railway transportation system should be prepared for planning comprehensive maintenance of the railway infrastructure, which allows coordinating structural units responsible for maintaining the railway infrastructure.

An important factor that affects the speed of defect formation and growth is the stress-strain state of the structural element being considered. Therefore, it is advisable to use mathematical modeling methods [10, 11, 12], which make it possible to estimate the stress-strain state of the structure for the real geometry of the wheel and rail.

To ensure the rapid detection of defects and the determination of priority work on their localization or timely replacement of defective rails, so as not to allow emergency situations in operation and to improve the reporting system on defects and damages for their research and analysis in the development of specific measures to increase the operational work of rails, a catalog of defects and damages of railway rails of Ukraine [13] has been developed and put into operation.

In curved sections of the railway track, additional forces of interaction with the moving rolling stock arise [14], which leads to an increase in stresses and strains in rails and as a result to the acceleration of defect formation and growth in rails.

To form a technical plan for servicing the railway infrastructure of various railway transport systems, the manager should have information on the types and patterns of accumulation of damages and defects in rails depending on the type of rolling stock and operating conditions.

The purpose and tasks of the study. The aim of the work is to establish regularities in the appearance of damages and defects in rails when interacting with various types of rolling stock and operating conditions. Establishing the main operational, design, and technological reasons for their appearance.

Tasks:

- conducting a statistical analysis of the appearance of damages and defects in rails in railway transport systems with different operating conditions;
- establishing the causes of damages and defects in rails depending on the design features of the rolling stock running gear and train operation modes.

Materials and methods of research. To compare the influence of rolling stock and operating conditions, rail defect data from the Kyiv Metro and mainline railway transport were analyzed. These data were obtained during periodic diagnostic measures of non-destructive rail testing.

When analyzing the operating parameters of these transport systems, it should be noted that the maximum axle load on the Kyiv Metro tracks is set at 150 kN, while the maximum allowable axle load for rolling stock on mainline railway tracks is 250 kN [15].

The operating conditions on the Kyiv Metro tracks are characterized by passenger rolling stock only, short interstation distances with a large number of accelerations and decelerations.

In turn, the operating conditions of mainline railway transport are characterized by a mixed traffic of passenger and freight trains with a higher average axle load.

We should also note that most of the operating sections of the Kyiv metro are located in tunnels, which ensures consistent operating conditions, ambient temperatures, and the absence of the influence of atmospheric phenomena such as rain, snow, wind, etc.

Data on detected defects on the rails of the Kyiv metro over five years of operation and on the tracks of the mainline railway over two years of operation were analyzed. The entire sample of data on detected defects was sorted by their code. We will analyze the detected defects separately for each year of the study, first for the tracks of the Kyiv metro, and then for the tracks of the mainline transport.

Figure 1 shows the distribution of defect codes detected in the rails of the Kyiv metro in the first year of the study.

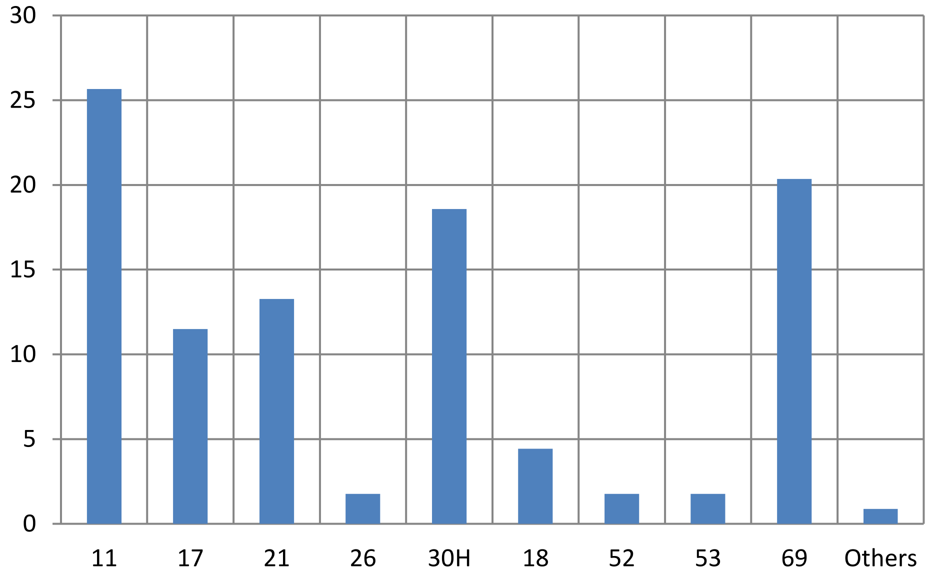

Fig.1. **Statistical distribution of detected defects in the rails of the Kyiv metro in the first year of the study**

As can be seen from the figure, the largest number (26%) is represented by defects with code 11. Slightly less defects were detected with codes 69 (20%) and 30H (19%). The number of defects with code 21 was 13%, and with code 17 - 11%.

Figure 2 shows the distribution of defect codes detected in the rails of the Kyiv metro in the second year of the study.

As can be seen from the diagram, the percentage of defects under codes 11 and 17 increased to 32%. The percentage of defects under code 21 was 11%, while defects under codes 30H and 19 were 7% and defects under code 69 were 6%. It should be noted that there were no defects under code 19 detected in the previous year.

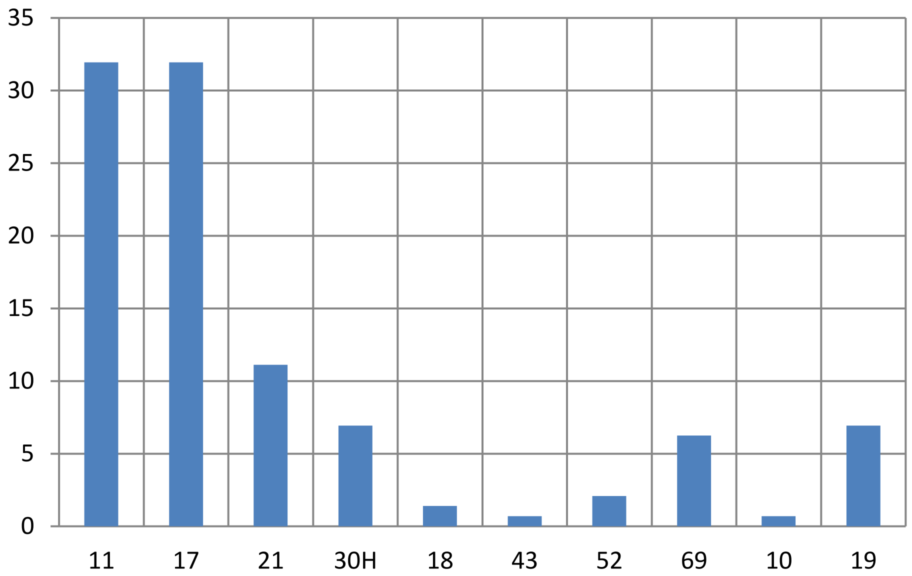

Fig.2. **Statistical distribution of detected defects in the rails of the Kyiv metro in the second year of the study**

Figure 3 shows the statistical distribution of defects detected in the rails of the Kyiv metro on the third year of research.

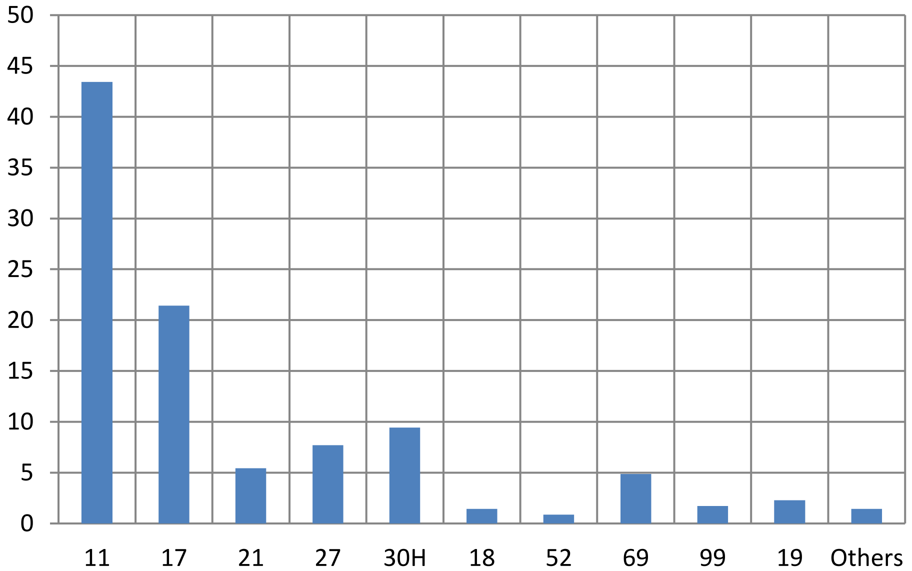

Fig.3. **Statistical distribution of detected defects in the rails of the Kyiv metro on the third year of the study**

On the third year of research, the percentage of defects detected under code 11 increased to 43%. The percentage of defects under code 17 also increased to 21%. The percentage of defects under code 30H was 10%. The number of defects under code 27 increased. While there were no defects under this code in the first and second years of research, their percentage of the total defects detected in the third year was 8%. Unlike the previous year, no defects under code 19 were detected. The percentage of defects under code 69 was 5%. Unlike the two previous years, defects under code 99 were detected, although their percentage was only 2%.

Figure 4 shows the statistical distribution of defects detected in the rails of the Kyiv metro on the fourth year of research.

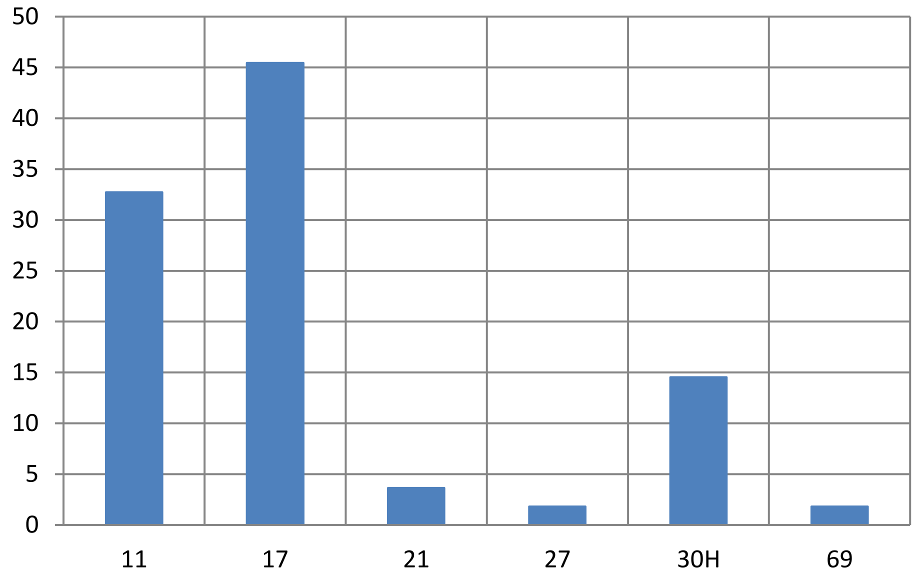

Fig.4. **Statistical distribution of detected defects in the rails of the Kyiv metro on the fourth year of the study**

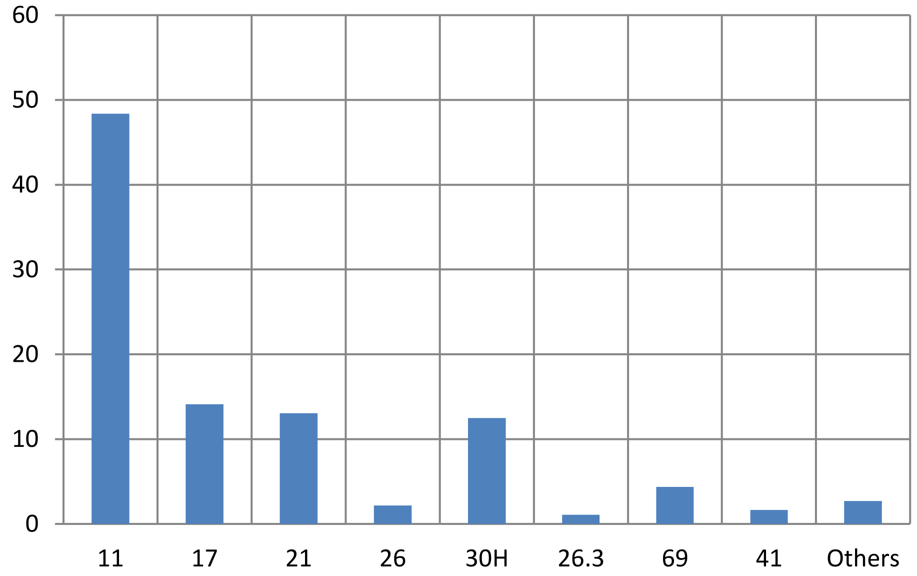

Fig.5. **Statistical distribution of detected defects in the rails of the Kyiv metro on the fifth year of the study**

The percentage of defects coded as 17 was 45%, 33% for code 11, and 14% for code 30H. No defects were found this year for codes 19 and 99.

Figure 5 shows the statistical distribution of defects detected in the Kiev Metro on the fifth year of research.

The highest proportion of defects were coded as 11, accounting for 48%. Defects coded as 17 accounted for 14%, 21 accounted for 13%, and 30H accounted for 13%.

Figure 6 shows the statistical distribution of defects detected on the mainline railway tracks in the first year of research.

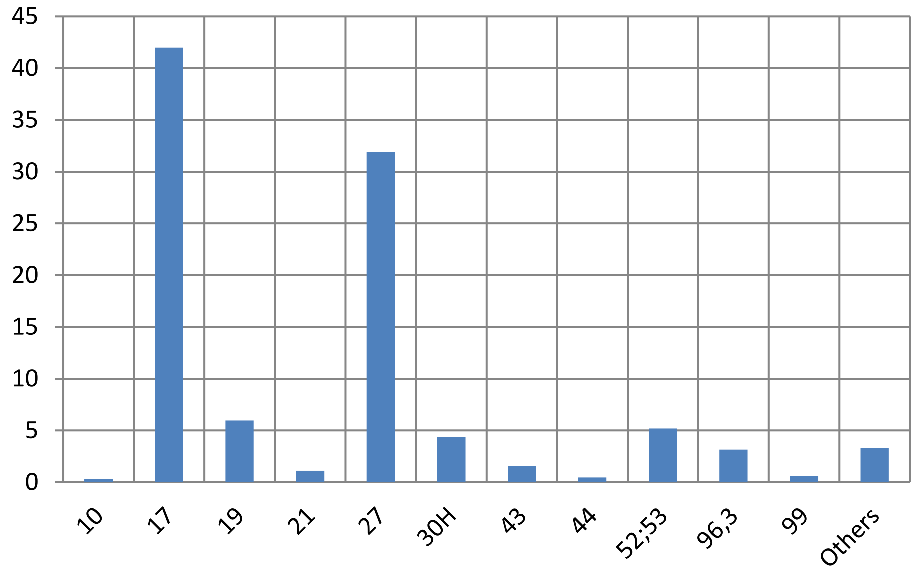

Fig.6. **Statistical distribution of detected defects in rails of the mainline railway transport in the first year of the study**

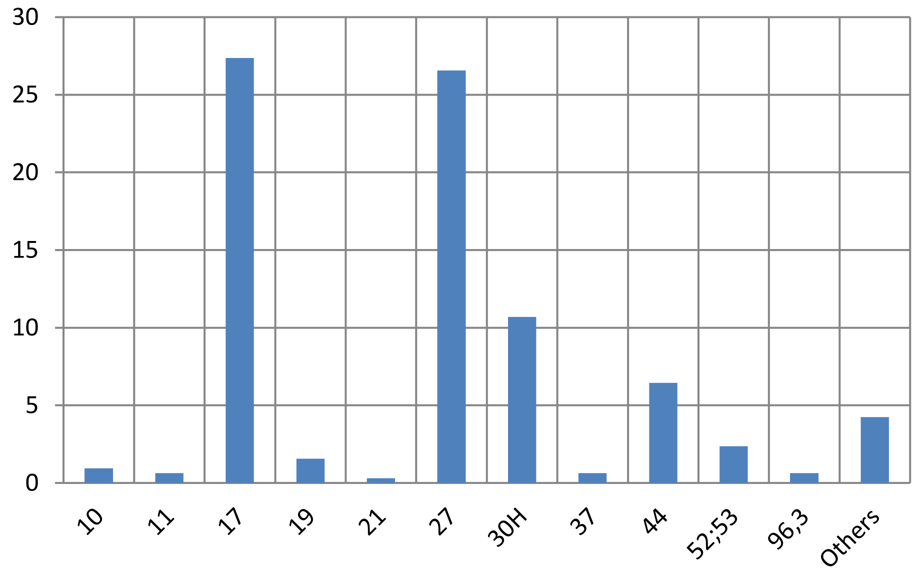

Fig.7. **Statistical distribution of detected defects in rails of the mainline railway transport in the second year of the study**

The highest number of defects were coded as 17, accounting for 42%, followed by 27 at 32%, 19 at 6%, 52 and 53 at 5.2%, and 30H at 4.4%. Figure 7 shows the statistical distribution of defects detected on the mainline railway tracks in the second year of research.

As shown in the diagram, the highest number of defects this year were coded as 17, at 27.4%. The number of defects coded as 27 sharply increased to 26.6%. The number of defects coded as 30H also increased to 10.7%. The proportion of defects coded as 44 accounted for 6.5%, while the proportion of defects coded as 52 and 53 decreased to 2.4%.

In summary of the analysis conducted, it can be noted that defects depicted in figures 10 and 11 are more common on the tracks of the Kyiv metro. Meanwhile, on the tracks of the main railway transport, defects depicted in figure 27 are more frequent, and a wider range of defects was observed, with none exceeding 5% frequency.

Conclusions. The dependence of the appearance of various types of damages and defects in rails on the design characteristics of the running gear of rolling stock and the operating conditions has been confirmed:

- on tracks within the urban transportation system, specifically in the metro, the more prevalent damages and defects include metal spalling or shelling on the rail head surface (constituting 26-48% of such defects). This is due to lower axle loads (150 kN) and a constant acceleration-braking regime between stations due to shorter distances;
- on mainline railway tracks, the following defects are more intensively observed: transverse cracks in the rail head with fractures across them, horizontal "H" and vertical "V" cracks in the rail head. This may be attributed to higher axle loads (up to 250 kN), maximum train speeds of 160 km/h, and train weights reaching 8000 tons.

The results of the conducted statistical analysis regarding the accumulation of rail defects and damages in the two transportation systems can be used for further scientific research in predicting the occurrence of rail defects under different operating conditions in both urban and mainline rail transport. These results should also be taken into account when developing technical, technological, and structural measures for their prevention.

To extend the service life of rails, an individual approach is necessary for the track maintenance system of each transportation system, considering its specific operating conditions.

Conducting scientific research using modern methods of computer modeling of the interaction between rolling stock and rail tracks in different transportation systems, taking into account the individual parameters of the wheel-rail system, will allow for determining the influence of structural and operational factors on the accumulation of defects and damages in rails.

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Олександр Агарков[1*], Володимир Твердомед[2]

[1]Доцент, Кафедра теоретичної та прикладної механіки, Державний університет інфраструктури та технологій, вул. Кирилівська, 9, м. Київ, 04071, Україна, ORCID: https://orcid.org/0000-0001-8250-6280

[2]Доцент, Кафедра залізничної колії та колійного господарства, Державний університет інфраструктури та технологій, вул. Кирилівська, 9, м. Київ, 04071, Україна, ORCID: https://orcid.org/0000-0002-0695-1304

Порівняльний аналіз пошкоджень і дефектів в рейках різних залізничних транспортних систем

У статті проведено аналіз накопичення виявлених пошкоджень і дефектів рейок двох транспортних систем – міського (метро) та магістрального залізничного транспорту. Підсумовуючи проведений аналіз, слід зазначити, що дефекти згідно з рисунками 10 та 11 частіше зустрічаються на коліях Київського метрополітену. При цьому дефекти згідно з рисунком 27 частіше зустрічаються на коліях магістрального залізничного транспорту, а також варто відзначити більш широкий спектр дефектів, частка яких не перевищує 5%. На думку авторів, це пов'язано з особливостями умов експлуатації транспортних систем, зокрема навантаженням на вісь рухомого обладнання, характеристиками руху та іншими експлуатаційними параметрами. Для більш точних висновків необхідно виконати ряд робіт з використанням методів математичного моделювання для врахування впливу окремих параметрів на накопичення дефектів і пошкоджень рейок.

Ключові слова: *рухомий склад, транспортна система, колісна пара, рейка, залізнична колія, дефект, пошкодження, втома, утворення тріщин.*