Proceedings of 26th International Scientific Conference. Transport Means 2022.

Methods of Assessment of Ballast Contamination on Railways of Ukraine

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Abstract

Ukrainian railways use a wide variety of methods for determining ballast contamination. Some regional branches of JSC "Ukrzaliznytsia" prefer to replace the old ballast with new instead of cleaning it. Others do the cleaning of crushed stone ballast. The periodicity of such crushed stone cleaning depends on local conditions and features of cargo transportation. Ballast contamination assessment plays an important role in this matter. The essence of the research is to reduce the time for obtaining results on the assessment of ballast contamination and to simplify it for use by one or two persons, who can act as track installers.
KEY WORDS: *ballast, railway track, crushed stone, ballast cleaning, sleepers*.

1. Introduction

Railway transport plays an important role in the economic development of the country and is the basis of its transport system. However, today railway transport is becoming less competitive with other types of transport, which is connected with global economic changes and the unfavorable economic situation that has developed in the state. Effective functioning of railway transport is a necessary condition for the stabilization and development of the economy and ensuring the national security of the country.

The process of European integration requires approximation to European transport quality standards, this primarily concerns the international transport corridors of Europe and Asia and the improvement of the economic efficiency of railway transport.

One of the ways to increase the competitiveness of railway transport is to reduce costs for its infrastructure. The share of railway track infrastructure in the entire railway transport system of Ukraine is significant. This especially applies to the costs of modernization and maintenance of the railway track by railway enterprises, which is associated with large investments

In European railways, it is believed that the most effective reduction of infrastructure costs is achieved by extending the life cycle of the track. Among the methods of extending the life cycle of tracks can be [1]:

– improving the initial quality of the track in order to distance the development of unevenness by using mechanized maintenance and high-quality materials, such as elastic elements and others, which ensure better operation of the ballast layer;

– planning of repairs and ongoing maintenance activities using effective planning strategies based on continuous monitoring of the development of the geometric state of the track and the use of automated work planning management systems.

2. Analysis of Ballast Layer Work Research

Two fundamentally different types of railway track are used on the world's railways: with a ballast layer and a ballastless base. On domestic public railways with a soil subgrade (more than 99% of the track length), the upper structure of the track with a ballast layer is the only structure that is used from both technical and economic indicators [2].

The main advantages of the ballast track are:

– proven technology;
– relatively low construction costs;
– easy replacement of track elements;
– relatively easy correction of track geometry (retention);
– small adjustments to the configuration (plan) of the railway track are possible;
– good drainage properties, elasticity and noise absorption [3].

As a result, the traditional ballast track superstructure still meets the high requirements, as demonstrated by the TGV tracks in France. The profitability of using a ballast track depends, first of all, on the performance of one of its main components, namely the ballast layer.

Ballast consists of a layer of unbound coarse-grained material, which, as a result of internal friction between the grains, can perceive significant compressive stresses, but not tensile stresses. The bearing capacity of the ballast layer in the vertical direction is significant, but it is clearly reduced in the lateral direction [4].

In addition to uniform distribution, the drainage property of ballast is very important [5-6]. Contamination of the ballast layer can have external and internal causes, such as abrasion, destruction of the ballast material under the influence of atmospheric phenomena or penetration of small particles in the form of a mixture of clay (loam). A contaminated ballast layer prevents the passage of water, which, as a result, reduces resistance to sliding and freezing during frost. The most important requirements for ballast material are: hardness, abrasion resistance, good particle size distribution. The particles should be cubic in shape and have sharp corners.

3. Influence of Factors on the Operation of the Ballast Layer

Based on the review of theoretical, laboratory and natural studies, conclusions are formulated about the generally accepted ideas about the operation of the ballast layer and the influence of the main factors on it [7-9]. In general, the operation of the ballast layer and railway track is influenced by a large number of primary and secondary factors. Including:

1) 1)operational: load tension, lost tonnage, axle load, speed of rolling stock, influence of rolling stock and condition of running parts;
2) factors depending on the track design: track stiffness, sleeper profile, condition and construction of the track substructure;
3) ballast layer factors: ballast material and its granulometric composition; pressure from the sleeper on the ballast layer, or horizontal and vertical stresses in the ballast; vibration effect on the ballast layer; initial compaction of the ballast layer; ballast contamination and moisture;
4) factors depending on track maintenance: permissible stress in the ballast layer; the initial quality of the track after repair (the quality of the track geometry and the ability to maintain this quality); quality of current maintenance and methods of its implementation (mechanized straightening and tamping of the ballast layer and their periodicity, grinding of the rolling surface of the rail, etc.).

Field tests make it possible to assess the influence of operational factors on the disruption of the track geometry without considering the processes that occur in the ballast layer. Laboratory tests make it possible to assess in detail the influence of load factors on individual sleepers and ballast properties on the settlement of the ballast layer. However, the assessment of the influence of factors on the operation of the ballast layer by laboratory tests has two main drawbacks. Firstly, the result is always the settlement of a single sleeper, while the unevenness on the track is the uneven settlement of many sleepers along the track, which also depends on the bending stiffness of the rails, uneven sleeper shoring, fluctuations in the rolling stock, uneven elasticity of the subgrade, etc. Secondly, for practical calculations, it is necessary to have a relationship between the operating factors and the load factors on the ballast layer or sleeper, that is, with a known speed, load tension, axial load, it is difficult to theoretically find the load on the ballast layer, the vibration effect on it, the degree of unloading or complete unloading in the presence of backlash.

A number of other factors can also be identified, but at the moment not all of them can be taken into account. Knowledge of the mechanisms of destruction and the influence of the listed factors on the operation of the ballast layer can provide an answer regarding the prediction of the disruption of the ballast layer and related planning of track works, optimization of its operation, selection of a combination of design parameters that best meet the given operating conditions. All this can significantly reduce the costs of construction and operation of the railway track.

4. Analysis of the Disadvantages of the Existing Methods of Assessing the Work of the Ballast Layer

At present, on the railways of Ukraine, when designing track structures or setting conditions for the rotation of rolling stock, the performance of the ballast layer is assessed by calculated stresses in the ballast layer and their permissible values, which can have different levels depending on the load tension, the type of fasteners and the type of rolling stock [10]. The approach based on the allowable stress criterion, which was adopted by analogy with the strength of other track elements, does not allow to fully assess the performance of the ballast layer. The main reason for this is the lack of clear boundaries between the operational and non-operational state of the ballast layer, as it continuously changes throughout its service life. The second reason is the failure to take into account the factor of current retention, which is decisive for the service life of the ballast layer. In addition, there are a number of other factors, without knowledge of which it is difficult to evaluate the performance of the ballast layer [6].

Thus, in summary, the following shortcomings of the assessment of the ballast layer can be identified [5, 10]:

1) calculated stresses in ballast and subgrade are much closer to their permissible stresses than in other elements and do not give an answer as to how the element will behave if the stresses are exceeded;
2) the ballast layer, unlike other track elements, is an element whose failure is the gradual deterioration of the track geometry;
3) a significant impact on the work of the ballast layer of track maintenance works;

4) permissible stresses are not related to the frequency of current maintenance work and the intensity of the accumulation of non-homogeneous residual deformations;

5) in addition to permissible stresses, an important factor is the initial quality of the track and its maintenance strategy;

6) the operation of the ballast layer is influenced not only by the maximum stresses in it, but also by the level of vibration, complete or partial unloading of the ballast in the presence of backlash, and many other factors;

7) unevenness that occurs on the track, or which was allowed, has an inverse reinforcing effect on the development of unevenness due to the disruption of the ballast layer;

8) the mechanisms of the destruction of the ballast layer under the sleeper are significantly different from the mechanisms of destruction of other elements to which the theory of resistance of materials is applied: the failure of the ballast layer occurs gradually in relation to the amount of backlash, the stiffness of the track at the place of the backlash, the loads on the ballast under the backlash and the dynamic by the action of the rolling stock.

5. Development of an Express Method for Determining the Degree of Ballast Contamination

Currently, the most diverse methods of ballast maintenance are used on roads. Some roads prefer to replace the old ballast with new instead of cleaning it. Other roads are cleaning crushed stone ballast from blast furnace slag and stone. The periodicity of such crushed stone cleaning depends on local conditions.

In some cases, crushed stone cleaning is done annually, and in other cases - only once every 12 years. Some roads periodically clean the ballast only on the slopes of the ballast prism and on the track, but do not clean it in the sleeper boxes. This practice is based on the assumption that the contaminant of the ballast in the sleeper boxes will be washed out by atmospheric water through the cleaned ballast on the slopes of the ballast prism and in the track. If the ballast on the slopes of the ballast prism and in the track is contaminated, then over time the ballast in the sleeper boxes also becomes contaminated. Some roads clean ballast from both sides of sleepers and in boxes, sometimes up to 8 cm below the bottom of the sleepers. Cleaning of ballast on the slopes of the prism is usually done 20-30 cm below the sole of sleepers, and when cleaning ballast on the track - 15 ... 20 cm Cleaning of ballast in sleeper boxes is usually done to a depth slightly below the sole of sleepers in the axis of the path and approximately 7.6 cm below the sole of the sleepers at their ends. Under such conditions, the contaminant in the ballast under the sleepers is washed away by atmospheric waters to the ends of the sleepers. To drain water from the ballast on the track, transverse drainage slots are used, with their slope corresponding to the slope of the prism. The distances between the slots, which should not pass under the rail joints, are usually equal to the length of the rail.

Various methods of cleaning contaminated ballast are used on roads. On some roads, only manual ballast cleaning is used; on other roads - only crushed stone cleaning machines on the rail course and machines that do not occupy the race. These machines clean the ballast on the slopes of the ballast prism and on the track. On a number of roads, ballast from sleeper boxes is first cut by hand or with the help of special machines and placed on the slopes of the ballast prism, and then it is cleaned here by a mechanized method. Ballast cleaning is done by roads or by own forces or under contracts with relevant companies.

The contaminant released during ballast cleaning dries quickly and usually turns into a material that is easily blown away by the wind. If the contaminant is thrown on the edge of the ground bed, it can be captured by the eddy currents of air that occur when trains pass, and, falling on the ballast, clog it again first of all on the slopes of the ballast prism, preventing the drainage of water from it.

In this regard, the contaminant must be thrown far below the slope of the embankments. When cleaning the ballast in the recesses, the contaminant must be removed beyond their limits. The contaminant can be left on the sides of the trenches only temporarily, for 1 ... 2 days.

Ballast cleaning in tunnels has specific features. The rise of the path in tunnels to clean ballast is limited by the conditions of the dimensions of the tunnel from above.

In long tunnels, the ballast is usually not only dirty, but also wet; therefore, many roads do not attempt to clean it, as it is difficult to separate the sticky contaminant from the crushed stone mass. In such cases, the ballast is completely removed and replaced with a new one. In short tunnels, the ballast is often dry and therefore easy to clean. Ballast cleaning is done manually on some roads.

In tunnels with good ventilation, special machines are used to cut ballast from the sleeper boxes and throw it to the sides on the slopes of the ballast prism, where it is cleaned with rubble-cleaning machines of the "Mole" type, or it is loaded with grab cranes on a rail run into wagons and taken out of the tunnel. On one road, for ballast cleaning in tunnels, a rail-mounted rubble-cleaning machine is successfully used, which cuts rubble from under the sleepers and from the slopes of the ballast prism, cleans it and puts it back on the road, and the contaminant is loaded with the help of conveyors into semi-wagons attached to the rubble-cleaning machine.

With this cleaning of crushed stone, the path is lowered by 1 cm, which allows you to make three lifts of the path to new ballast in the future.

In places where manual cleaning of crushed stone is planned, local conditions should be carefully studied, because with the existing high cost of labor, it is sometimes more profitable to replace contaminated ballast with new ones instead of cleaning it by hand. Manual cleaning of crushed stone is done according to the following technology. First, the crushed stone is loosened with a pick at the ends of the sleepers to a depth of about 15 cm below the bottom of the sleepers. Then the ballast is taken on forks and, by shaking, the contaminant is separated from it. Cleaned crushed stone is placed in the middle of the path, where it is used when raising the track. The brought clean crushed stone is unloaded on the slopes of the ballast prism. In those cases when the crushed stone in the sleeper boxes is very dirty, it is cut with picks and shovels slightly below the bottom of the sleepers. Manual cleaning of crushed stone is inefficient, very expensive and tiring for the workers. In addition, no matter how carefully the crushed stone is cleaned on the forks, some amount of the contaminant remains in it or in the process of cleaning it gets back into the path. The average rate of production of one worker on cleaning crushed stone by hand is about 4.9 m of path in an eight-hour working day. At one time, manual rubble cleaning was used on many roads using the following technology. The dirty crushed stone was loosened with picks and shoveled onto the sieves installed at an angle on the side. The contaminant fell on the roadside and was then dumped on the slopes of the embankment, while the clean crushed stone rolled down the inclined surface of the screens to the base of the ballast prism and was then placed on the road. Works based on this technology had a high cost and low productivity. Therefore, in order to reduce the cost of work and increase productivity, screens began to be installed on railway platforms. Contaminated crushed stone was thrown onto these sieves with the help of grab cranes on the rail course. Clean crushed stone was rolled back to the road on inclined screens, and the contaminant that passed through the screens remained on the platforms

6. Conduct of Research on Ballast Contamination

Conducting an experiment

To carry out the express method for determining the contamination of the ballast layer, two sections of track were taken: Section A (119 km of even and odd track), Section B (135 km of odd track).

Characteristics of the site A

Fraction: 25 ... 60 mm.

Cleaning was performed by RM-80 in 2018.

The missed tonnage is 876 million gross tons. Load volume – 38.3 million gross tons per year.

Track category - II. Track type: P65, non-contact.

Fastening: double track – KB; odd track – KPP 5.

Speed: V_{pas} – 80 km/h; V_{load} – 60 km/h;

Characteristics of the site B

Fraction: 40 ... 70 mm.

Cleaning was performed by RM-80 in 2015.

The missed tonnage is 259,2 million gross tons. Load volume – 53.8 million gross tons per year.

Track category - II. Track type: P65, non-contact.

Fastening: double track – KB; odd track – KPP 5.

Speed: V_{pas} – 100 km/h; V_{load} – 80 km/h;

During the research, a sieve with 0.5 (mm) holes was used, and electronic weights up to 2 kg, and with a measurement step of 1 gram.

The essence of the research is to reduce the time for obtaining results on the assessment of ballast contamination, and to simplify it for use by one or two persons, who can act as track installers. During the research, 20 samples were taken on each section of the track, 10 in the sleeper box, and 10 in the end of the sleeper at a depth of 20 cm, with different characteristics of the track and with differences in plantings.

After sieving, the following numerical values were obtained (Tables 1-6).

Table 1

Site A is even

Even track in the sleeper box		
Sample weight (g)	Net weight (g)	Contamination, %
989	886	10,4
993	898	9,6
987	896	9,2
999	899	10,0
989	888	10,2
994	894	10,1
995	896	10,4
999	902	9,7
999	901	9,6
1007	900	10,6
1002	904	9,8
989	887	10,3

Table 2

Site A is even

Even track at the end of the sleeper		
Sample weight (g)	Net weight (g)	Contamination, %
1006	972	3,4
1001	969	3,2
988	960	2,8
996	965	3,1
991	964	2,7
997	965	3,2
996	964	3,1
994	967	2,7
1003	974	2,9
986	960	2,6

Table 3

Site A is odd

Odd track in the sleeper box		
Sample weight (g)	Net weight (g)	Contamination, %
996	911	8,5
999	920	7,9
1002	926	7,6
1001	919	8,2
999	907	8,4
998	917	8,1
994	901	8,1
997	917	8,0
997	919	7,8
991	913	7,9
990	915	7,6

Table 4

Site A is odd

Even track at the end of the sleeper		
Sample weight (g)	Net weight (g)	Contamination, %
997	976	2,1
1003	989	1,4
1004	984	2,0
989	975	1,4
996	979	1,7
994	977	1,5
992	976	1,6
988	964	1,9
987	969	1,8
993	972	2,1
995	976	1,9

Table 5

Site B

Odd track in the sleeper box		
Sample weight (g)	Net weight (g)	Contamination, %
987	925	6,3
993	926	6,7
989	929	6,1
1006	937	6,9
992	934	5,8
997	937	6,0
991	929	6,3
1001	939	6,2
989	924	6,6
993	932	6,1

Table 6

Site B

Odd track at the end of the sleeper		
Sample weight (g)	Net weight (g)	Contamination, %
986	969	1,7
1003	988	1,5
997	986	1,1
993	979	1,4
993	977	1,6
996	984	1,2
991	977	1,4
994	981	1,3
986	976	1,0
995	983	1,2

According to the experimental data, numerical values were obtained on 3 sections of the track.

6...8 man-hours per 1 km of track were spent on the work.

We will compare the contamination in the sleeper box and at the end of the sleeper (Figs. 1-3), and the graphs are drawn for 10 pickets with the most characteristic values.

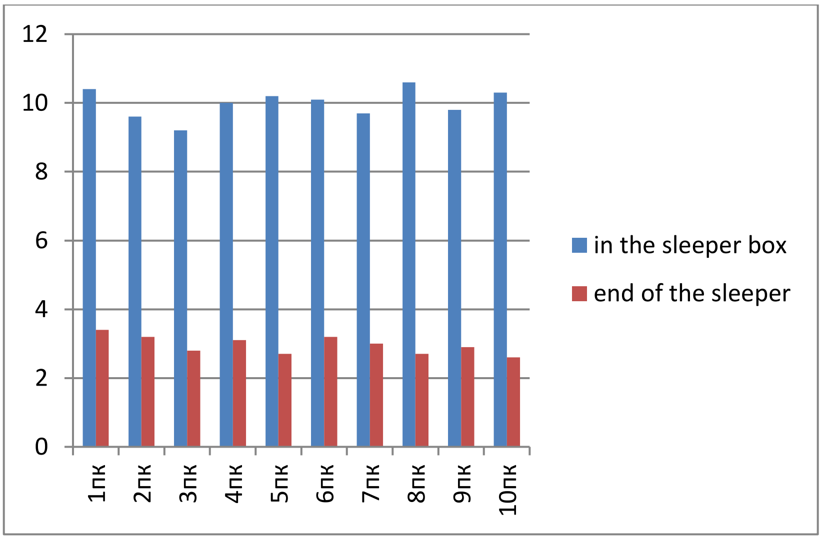

Fig. 1 Comparison of ballast contamination in the sleeper box and at the end of the sleeper

To this graph (Fig. 1), it can be concluded that the contamination of the ballast in the sleeper box is greater, almost 3 times, than in the end of the sleeper.

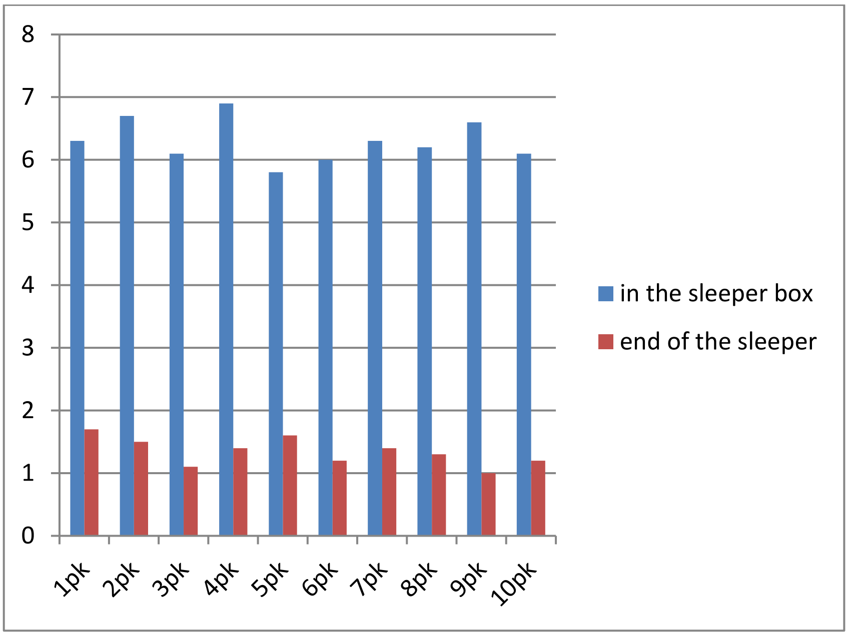

Fig. 2 Comparison on the site with the crushed stone fraction 40-70

This graph (Fig. 2) makes it possible to testify that with a fraction of 40 ... 70 mm, the contamination in the sleeper box is greater than in the end of the sleeper.

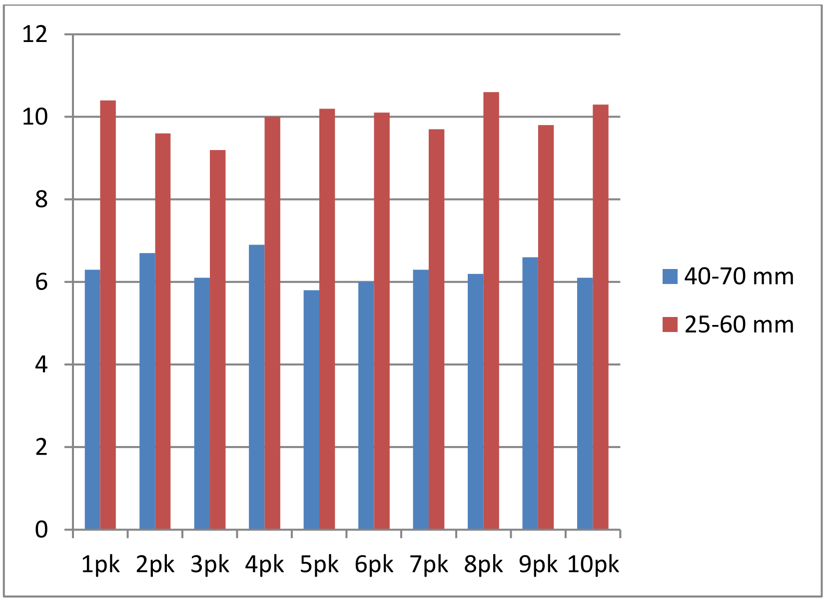

Fig. 3 Comparison of contamination of track sections with 40 ... 70 mm and 25 ... 60 mm ballast

On this graph (Fig. 3) we can see that the section of the track works better on ballast with a fraction of 40 ... 70 mm than on a fraction of 25 ... 60 mm.

During the implementation of the express method for determining ballast contamination, it was determined that 1 km of track, 1 track fitter can check the contamination of 1 km of track in 1 working day.

7. Conclusions

During the implementation of the express method, the following conclusions were made: the maximum contamination at the end of the sleeper is 3.4%; the maximum contamination in the sleeping box is 10.4%; contamination at the end of the sleeper is less than contamination in the sleeper box; time spent on carrying out the express method is 4 ... 8 man-hours per 1 km.

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