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Modelling the Operation of a Ballast Prism with Under-Sleeper Pads

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ABSTRACT

An important condition for operation of extra heavy-duty lines is to ensure the stability of the track geometry, including in the vertical plane, which largely depends on the stability of the sleeper base and on the absence of residual deformation of the ballast layer.

The article refers to the analysis of the results of a study on reducing residual deformations of the ballast layer using sleeper pads. The objective of the work is to assess their impact on the operation of the ballast prism during the stabilisation period and the period of its normal operation. The laboratory tests allowed obtaining a stamp settlement graph, determining the intensity of its settlement, measuring the contact area of the stamp sole with the ballast, calculating contact stresses, constructing a graph of the change in the elastic modulus of the model.

The results of the study have revealed that sleeper pads help to reduce residual deformations of the ballast layer during its stabilisation period and the intensity of settlement during the main period of its operation.

Keywords: *railway track, sleeper pads, track elasticity modulus, ballast layer, rail settlement, residual ballast deformations.*

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The original text of the article in Russian is published in the first part of the issue.
Текст статьи на русском языке публикуется в первой части данного выпуска.

BACKGROUND

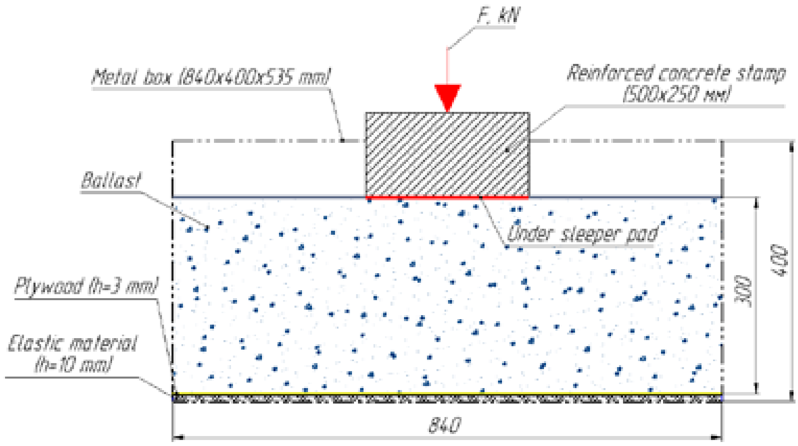
The stability of the track geometry is an important condition for the safe operation of railways with intensive traffic and large volumes of cargo transportation. This applies to an even greater extent to lines with particularly high cargo traffic volumes [1], the length of which, for example, on the network of JSC Russian Railways is currently 16 thousand km [1].

Several works of researchers of the Railway Research Institute of JSC Russian Railways [2–5] were devoted in the second half of 20th century to the studies of the accumulation of residual deformations in the ballast layer, that helped to shape the basic understanding of the operation of this element of the track structure. Considering the operation of the ballast layer of the railway track, S. N. Popov pointed out that to ensure long-term stability of the sleeper base on lines with high cargo traffic volumes, it is necessary to have a track design in which the ballast layer along the entire length of the track would operate with uniform accumulation of residual deformations [2]. Studying the nature of accumulation of residual deformations of the ballast layer during its life cycle, he identified four characteristic periods, which he described as follows: during the period 1 (the stabilisation period), there is an intensive accumulation of residual deformations due to the realigning (repackaging) of grains and the rounding of their sharp edges, both processes decreasing sharply towards the end of the period. During the period 2 (the normal operation period), the accumulation of residual deformation becomes minimal. The period 3 is characterised by an increase in the accumulation of residual deformations, which is associated with the contamination of the crushed stone by the end of its service life. During period 4, there is an excessively intensive accumulation of settlement, which occurs due to failure to perform timely repairs to the track.

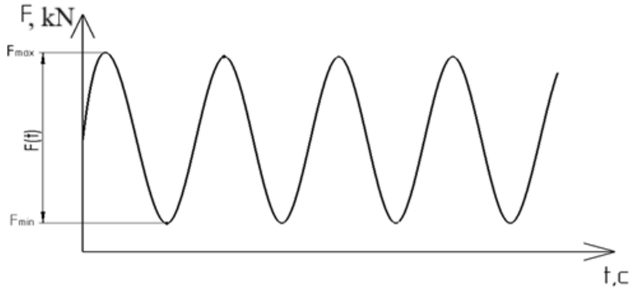
V. I. Lysyuk considered that the main reason for the accumulation of residual deformations in the ballast during operation was due to the dynamic impact of trains on the track [3], which is stronger, the higher is the rigidity of the superstructure. An example of an increase in track rigidity is the transition from wooden sleepers to reinforced concrete ones. This change in design resulted in an increase in the dynamic impact of trains on the track and, accordingly, in a growing intensity of accumulation of residual deformations in the ballast layer, which was noted in the work of V. F. Fedulov [4]. The greatest problems in this case arise with dynamic impact in the area of the rail joint. To solve them, the work [5] proposed to achieve a reduction in residual deformations of the ballast by installing an elastic connection along the lower support surface of the reinforced concrete sleeper, which will improve the conditions of contact of crushed stone particles with the sole of the sleeper, reduce its crushability and abrasion.

In some countries, on a few sections, stress reduction in the ballast layer is achieved by using under-sleeper pads (hereinafter referred to as USP) [6]. In Russia, studies of the efficiency of

[1] SP [Code of rules] 119.13330.2012. 1520 mm gauge railways. Updated version of SNiP 32–01–95 [Construction norms and rules] Railways with 1520 mm track. [In Russian]. [Electronic resource]: https://docs.cntd.ru/document/1200095541?ysclid=m7endujtqq310261972. Last accessed 21.08.2024.



Pic. 1. Scheme of the laboratory model structure [performed by the authors].



Pic. 2. Scheme of the laboratory model structure [performed by the authors].

USPs started in the middle of 20th century [5; 7; 8], but they were mainly aimed at ensuring track stability in the areas of rail joints. Namely, the work of V. N. Kaplin [9] confirmed the technical and economic efficiency of using USPs when straightening the track at joints.

At the current stage of increasing train loads on the track, it is necessary to study the efficiency of using USPs outside the area of rail joints, considering a possibility of reducing the accumulation of deformations in the conditions of a continuous track, and that is the *objective* of the study.

Based on the above characteristics of four periods of operation of the ballast prism, formulated by S. N. Popov, it can be assumed that USPs, due to the reduction of contact stresses, should reduce the settlement of ballast layer during periods 1 and 2 of its operation, and will not have an effect on periods 3 and 4, since the main influence on the increase in settlement at this time is its contamination.

To confirm the presented hypothesis, it was decided to conduct a laboratory experiment with the purpose to determine the effect of USPs on periods 1 and 2 of the ballast layer operation.

RESULTS

Test conditions

The modelling of the ballast layer operation was performed as a modelling in two-dimensional space, where the plane of modelling is assumed to be the plane along the track in the under-rail zone. The possibility of conducting such an experiment was confirmed in the work [10] when studying the deformation properties of contaminated ballast.

The model diagram is shown in Pic. 1.

The model was assembled in a metal box with the following dimensions: along the track axis – 850 mm (the minimum dimension to eliminate the influence of boundary conditions), across the track axis – 535 mm (the smallest dimension for crushed stone testing should exceed the maximum size of the crushed stone particles by at least 5 times [11]), height – 400 mm.

A 10 mm thick elastic mat was placed at the base of the box, which modelled the main platform of the roadbed (hereinafter – MPRB). To eliminate local deformations, 3 mm thick plywood was placed upon the elastic layer. This design made it possible to achieve a deformation modulus of MPRB of 80 MPa. The thickness of the ballast layer was 30 cm.

At the next stage, granite crushed stone type 2 was laid layer by layer, the grain composition of which complied with GOST [State standard] 7392[2]. The layer thickness was 100 mm. Each layer was compacted using a wooden stamp measuring 830 x 525 mm. The first two layers were subject to 10 thousand load cycles, the third layer – to 500 thousand load cycles. The graph of load application is shown in Pic. 2. The load application frequency was 8 Hz. This compaction mode allows achieving the best compaction [12].

After compaction, a reinforced concrete stamp was installed. To ensure real contact between the sleeper and the ballast, the stamp was cut out of the middle part of the sleeper of the Sh3-Д 4x10 subtype. A photo of the assembled model is shown in Pic. 3.

During the experiment itself, the model was subjected to the load in the same mode as during compaction, as it is shown in Pic. 2. The maximum force allows achieving permissible stresses under the sleeper sole caused by the wagons equal to 325 kPa. This stress value is established in the Methodology for assessing the

[2] GOST [State standard] 7392–2014. Crushed stone of rocks for railway ballast. Specifications. [In Russian]. [Electronic resource]: https://files.stroyinf.ru/Data2/1/4293762/4293762301.pdf?ysclid=m872wmf7pk430161462. Last accessed 21.08.2024.

Pic. 3. Assembled laboratory model [photo taken by the authors].

Pic. 4. Appearance of soft-type USP after testing [photo taken by the authors].

impact of rolling stock on the track based on conditions of ensuring dependability[3] (hereinafter referred to as the Methodology).

The number of cycles in the experiment was 2 million.

The load impact frequency was 8 Hz. The adopted impact frequency was based on the following assumed parameters: a bogie base of 1850 mm and an average speed through the network of 55 km/h (15,28 m/s).

Three experiments were performed, which had differences in the area of the contact between the stamp sole and the ballast:

– Model No. 1 – without USP.

– Model No. 2 – with USP of a soft type.

– Model No. 3 – with USP of an intermediate type.

The assembly of each of the presented models was carried out according to the description presented above.

[3] Methodology for assessing the impact of rolling stock on the track based on conditions of ensuring dependability, approved by the order of JSC Russian Railways, dated 22.12.2017, No. 2706r. [In Russian]. [Electronic resource]: https://meganorm.ru/mega_doc/norm/metodika/0/metodika_otsenki_vozdeystviya_podvizhnogo_sostava_na_put_po.html. Last accessed 27.08.2024.

USPs were made of polyolefin material, 10 mm thick and with a distributed static modulus of elasticity of 0,14 N/mm^3 (soft type) and 0,24 N/mm^3 (intermediate type).

USP types comply with the specifications 02.2020 adopted by Central infrastructure direction of the JSC Russian Railways.

RESULTS OF THE LABORATORY EXPERIMENT

After the completion of the experiment, a visual inspection of the condition of USP was carried out. It is worth noting that, after conducting cyclic tests under a load that causes the maximum permissible stresses under the sleeper sole, there were no through breakdowns or cracks on the USPs. Pics. 4 and 5 show photos of USP after the tests.

Pic. 6 shows a graph of the stamp settlement regarding three models, that evidence that the ballast settlement at the end of the first period of its operation decreased in the models with USP by approximately two times.

The stamp level marks at the end of the first period of operation and at the end of the experiment were listed in Table 1 to assess the efficiency of using the USP.

Pic. 5. Appearance of intermediate-type USP after testing [photo taken by the authors].

Table 1

Intensity of stamp settlement [performed by the authors]

Model	The value of settlement after the end of the first period (per 100 thousand cycles), mm	Stamp settlement after 2 million cycles, mm	Intensity of settlement during the second period, mm/mln of cycles
Without USP	7,70	9,75	1,03
With intermediate-type USP	4,28	6,38	1,00
With soft-type USP	3,22	5,05	0,92

The analysis of the results shown in Table 1 reveals that the use of intermediate-type USP allowed to reduce the stamp settlement at the end of the first period of the ballast prism operation by 44 %, and the use of the soft-type USP – by 58 %. It should also be noted that the use of USPs led to a decrease in the intensity of the stamp settlement during the second period of the ballast prism operation. Thus, intermediate-type USPs reduced the intensity by 3 %, and soft-type USPs – by 11 %.

No differences were found in the change in the grain composition of crushed stone between three models after the experiment (Table 2). This result can be explained by the consequence of the application of the ballast compaction before the experiment itself, which led to the formation of a fine fraction at the preparatory stage, due to the fragments of calved sharp edges of crushed stone's grains. As a result, it can be concluded that USPs affect the state of crushed stone by reducing the number of fragments of calved sharp edges, which is obtained due to the distribution of stresses over a larger area.

To determine the contact stresses, the areas of contact between the crushed stone's grains and the lower surface of the sleeper were measured in the ballast using the raster method. The values of the areas of contact and contact stresses are shown in Table 3.

The result showed that when using under-sleeper pads, the area of contact of the crushed

Table 2

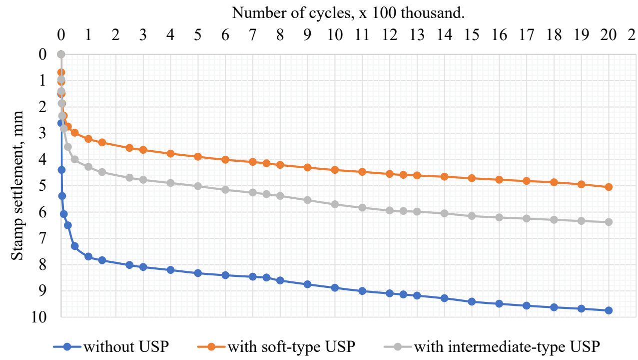
Change in grain size structure of crushed stone [performed by the authors]

Sieve opening, mm	Before testing		After testing					
			Without USP		With soft-type USP		With intermediate-type USP	
	%	kg	%	kg	%	kg	%	kg
60	1,6	4	1,6	4	1,6	4	1,6	4
40	73,4	183,5	72,9	182,3	72,5	181,2	72,9	182,3
25	25	62,5	25	62,4	25,5	63,7	24,9	62,3
from 0,01 to 25	-	-	0,5	1,3	0,5	1,2	0,5	1,4
Total	100	250	100	250	100	250	100	250

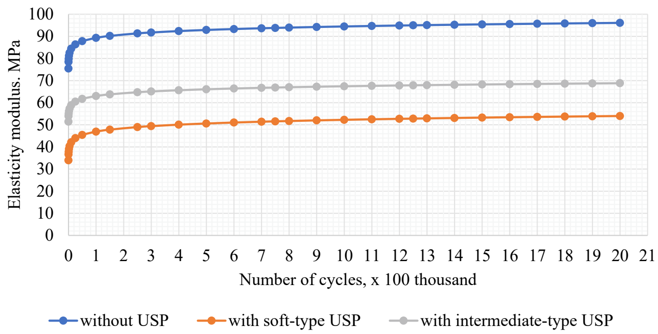
Table 3

Area of contact area of the stamp sole with the ballast [performed by the authors]

Parameter	Without USP	With soft-type USP	With intermediate-type USP
Area of contact of the stamp sole with the ballast, %	9	20	20
Contact stress, MPa	3,61	1,63	1,63



Pic. 6. Stamp settlement graphs [performed by the authors].



Pic. 7. Change in the elastic modulus of the model [performed by the authors].

stone with the sleeper increased by 2,20 times, and therefore, the contact stresses dropped by the same amount. Accordingly, this reduction in stresses will entail a decrease in the number of fragments of calved sharp edges of crushed stone's grains, their rearrangement, and, consequently, will increase the stability of the railway track in the vertical plane.

In addition to the data provided on the accumulation of residual settlement, the change in the elastic modulus of the track during the experiment was determined for each model using formula (1):

$$U = \frac{\alpha\omega C}{l}, \quad (1)$$

where α – sleeper bending rate, i.e. the ratio of the average settlement of a sleeper to its settlement under the rail;

ω – area of half-sleeper;

C – sleeper's lower surface rate;

l – distance between sleepers.

In turn, the sleeper's lower surface rate *C* was calculated using formula (2):

$$C = \frac{\Delta F}{\Delta y\omega}, \quad (2)$$

where ΔF – average increment in load on half-sleeper;

Δy – corresponding displacement increment.

In formula (1), the bending rate α for the stamp was taken to be equal to 1, the area of the half-sleeper ω was taken to be equal to 0,125 m (the area of the stamp base), and the distance between the sleepers corresponds to the distribution of 1840 pcs/km.

In formula (2), ΔF is the difference between the maximum and minimum load applied to the stamp, and the value Δy was obtained experimentally and is the difference in the displacement of the stamp at the minimum and maximum values of the applied force.

Pic. 7 shows a graph of the change in the elastic modulus of the track for each model, calculated using formula (1) throughout the experiment.

The graph shows that the model without a UPS has an elastic modulus close to 100 MPa, which is consistent with the data given in Methodology[2] for a railway track laid on reinforced concrete sleepers. Analysing the graph, it is possible to state that the use of soft-type pads reduces the elastic modulus of the track almost two times and brings it closer to the track laid on wooden sleepers, which is considered optimal for the interaction of the track and rolling stock.

CONCLUSIONS

The experiment confirmed the previously stated hypothesis about the reduction of residual settlement of the ballast layer when using the soft-type USP. At the same time, after 2 million loading cycles, the value of the residual settlement of the ballast layer decreased by 1,5 times with the intermediate-type USP and by 1,9 times with the soft-type USP.

The area of contact between the sole of the reinforced concrete stamp and the crushed stone when using the soft-type USP increased by about 2 times, which reduced the contact stresses on the crushed stone by the same ratio and, accordingly, reduced the risk of its abrasion.

The value of the elastic modulus of the track in the experiment for the model without the USP was obtained close to the value of a similar modulus adopted in the calculations according to Method[2], which indicates the correctness of the experimental results.

The elastic modulus of the track when using the soft-type USP decreased to the values of the elastic modulus of the track laid on wooden sleepers, which is considered optimal for the interaction of the track and rolling stock.

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