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DETERMINING THE ENERGY OF IMPACT OF A RAILROAD ROLLING STOCK WHEELSET WHEN DERAILING OVER REINFORCED CONCRETE SLEEPERS USING IMPACT TRACE PARAMETERS

Yaroslav Bolzhelarskyi
PhD, Associate Professor*
Josyp Luchko
Doctor of Technical Sciences, Professor
Department of Building Constructions
Lviv National Environmental University
V. Velykoho str., 1, Dubliany, Ukraine, 80381
Olena Bal
PhD, Associate Professor*
Vitalii Kovalchuk
Corresponding author
Doctor of Technical Sciences, Associate Professor*
E-mail: kovalchuk.diit@gmail.com
*Department of Railway Transport
Lviv Polytechnic National University
S. Bandery str., 12, Lviv, Ukraine, 79013

The object of research is reinforced concrete sleepers that are subjected to the impact of a wheel in a railroad rolling stock.

A procedure is given to theoretically estimate the energy at the impact of a wheel into a reinforced concrete sleeper when a rolling stock wheelset derails.

Experimental studies of the geometric parameters of impact traces that occur on reinforced concrete sleepers, depending on the height of the center of mass of the striker above the impact site, were conducted. Based on the results of the experiments, the average geometric parameters of the impact traces were obtained. It was established that the dependence of impact traces on the height of the center of mass of the striker above the place of impact into the reinforced concrete sleeper has a non-linear distribution.

Experimental studies of the effect of the location of the reinforced concrete sleeper base on the geometric parameters of impact traces were conducted. It was established that the location of the reinforced concrete sleeper on a solid base and on crushed stone ballast does not exert a significant effect on change in the geometric parameters of impact traces. The obtained experimental values are within the limits of 3σ determined for the rigid abutment of the sleeper.

It was established that when testing a reinforced concrete sleeper in a crushed stone box, the amount of energy depends on the height of the striker. At a height of 0.95 m, the amount of energy absorbed by the sleeper together with the ballast was 475 J, and at a height of 1.42 m – 710 J.

Analytical dependences were obtained between the length of the face of the impact trace and the amount of absorbed energy, as well as the depth along the direction of the force and the amount of absorbed energy. It was established that the length of the impact trace has an extremum, which does not allow recommending this parameter for estimating the amount of absorbed energy for energy values E<200 J. To determine the amount of energy absorbed by the sleeper, it is recommended to use the parameter of the depth of the impact trace

Keywords: reinforced concrete sleepers, impact traces, derailment, railroad rolling stock

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1. Introduction

When the rolling stock derails, the wheelset, rolling off the head of the rail, exerts a shock impulse on the reinforced concrete sleeper. As a result, reinforced concrete sleepers are damaged in the form of impact traces from wheelsets (Fig. 1). Impacts of the wheel on the sleepers are also observed during further movement of the wheelset on the rail-sleeper grid.

A wheelset in the state of derailment can continue to move for hundreds, and in some cases thousands of meters until the moment when it encounters a significant obstacle (turnout, railroad crossing, etc.) [1].

At the same time, there are impacts of the wheelset on the sleepers, which is accompanied by the appearance of additional movement resistance due to the dissipation (scattering) of energy. Under traction mode, the specified energy loss is compensated by the locomotive to maintain the set speed. Under advancing mode, additional resistance will lead to an increase in the amount of deceleration, and under the braking mode – to a decrease in the braking distance [2].

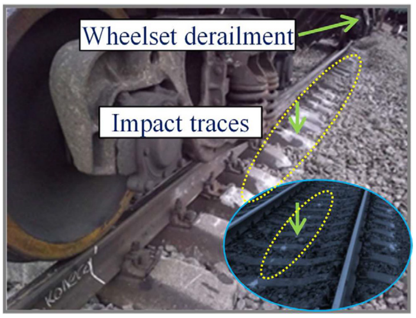


Fig. 1. Traces of interaction between sleepers and railroad wheels after derailment

Estimating the amount of additional movement resistance that occurs as a result of wheelsets hitting sleepers is important from the point of view of establishing the circumstances of a railroad accident. The lack of a methodology for calculating the additional resistance that occurs when a wheelset moves along a rail-sleeper grid reduces the accuracy of traction and braking calculations in the event of derailment and rolling stock collisions. This, in turn, makes it impossible to establish the place of the start of brake application and to determine the possibility of preventing a railroad accident.

In addition, the estimation of the additional movement resistance that occurs during descent is important to design devices for detecting derailed wheelsets in a moving train.

Since the movement resistance is related to the energy that is absorbed during impacts, estimating the amount of absorbed energy based on the parameters of the traces is an urgent task of scientific research.

2. Literature review and problem statement

The task of improving traffic safety in railroad transportation is well-known; it is addressed in many aspects, among which, in the context of the current study, the issue of dynamic interaction between rolling stock and track should be highlighted.

The dynamic interaction of traction rolling stock and track from the point of view of traffic safety is analyzed in [3, 4]. The contact interaction of the railroad wheel rim with the rail track is analyzed in [5, 6]. A characteristic feature of these works is the consideration of dynamic interaction under normal driving conditions, that is, before the rolling stock derails.

The study of train movement after derailment and the interaction of wheelsets with the under-rail base are relevant. First of all, this is relevant for countries where there is a high probability of earthquakes, and the associated probability of derailment of rolling stock, including high-speed (China, Japan, Korea). The efforts of scientists in these countries are focused on the development of methods to reduce the consequences of rolling stock derailments by implementing various types of derailment containment provisions (DCP). At the same time, both the movement of the train after derailment as a whole and the contact interaction of the derailed wheel and the under-rail base are analyzed.

An overview of scientific works that analyze train movement after derailment in order to improve the means of restraining trains after derailment is given in [7]. In each of the above works, the schemes of contact interaction of the derailed wheel with elements of the railroad infrastructure are analyzed but the purpose of this analysis is primarily to substantiate the parameters of the specified means.

In [8], the dynamic behavior of a wheelset that has come off the rails and is moving along the rail grid in the space between the rail and the counter rail is considered. A corresponding mathematical model was built. However, the main focus of the study is on the interaction of the derailed wheel with the rail, and not with the sleepers. The shape of the tracks on the sleepers is not analyzed.

In [9], the dynamic behavior of the train after derailment is considered and the case of collision of the train with elements of the adjacent infrastructure is analyzed. The effect of the coefficient of friction between derailed wheels and reinforced concrete sleepers on the speed of train parts after derailment and their final position after derailment is considered. At the same time, the trace pattern, and the procedure of determining the coefficient of friction are not considered.

In [10], the results of a full-scale experiment on derailment of a freight car trolley are reported. The peculiarity of the work is that it examines an 18-xxx type cast bogie with cast elements, which is used in the rolling stock of Ukrainian railroads. The authors analyze in detail the process of derailment of the specified bogie and its subsequent movement, however, the tracks from the rails are simply fixed but their parameters are not analyzed. Also, the relationship between the acceleration, impact force, and speed of the bogie and the size and type of damage to the rail-sleeper grid is not investigated. It should also be noted that a ballastless construction of a railroad track with sleepers embedded in a concrete foundation is being considered.

In [11], the behavior of the platform of a container ship after derailment is analyzed. The results of a full-scale experiment are presented, the acceleration of the car and the forces with which the running parts of the car affect the elements of the restraint system after derailment are determined. However, the article does not analyze the effect of a derailed car on the under-rail base.

In [12], the parameters of the traces left by the wheelset on the surface of sleepers are considered in detail. The results of modeling and the dependence of the shape and size of damage on the speed and mass of the train are given. However, the work does not consider the issue of determining energy losses from impacts and destruction of sleepers and the additional resistance to train movement that occurs in this case.

In [13], the results of static and shock experiments on the simulation of the collision between a railroad wheel and a sleeper are reported. In this case, a contact shoe in the shape of a wheel is used. The article shows the relationship between effort and the depth of the tracks, but the energy consumption was not determined. In addition, in these experiments, the force was applied strictly vertically, which does not correspond to the actual application of shock forces when the wheel moves along the rail-sleeper grid, and the placement of the sleeper in the ballast was not taken into account.

In [14], the results of an experiment similar in essence to [13] are considered, but reinforced concrete sleepers with the addition of rubber filler are tackled. The amount of absorbed energy was determined, and the nature of the damage was analyzed. As in work [13], the shock load was applied vertically, which does not correspond to the direction of the actual impact of the wheel on the sleeper when derailing. The presence of ballast was also not taken into account.

In [15], using the method of discrete elements, a simulation of the interaction between a wheel and crushed stone ballast was carried out. The energy absorbed by the ballast was determined by calculation and experiment. The authors note the importance of studying the parameters of wheel tracks on the ballast but do not take into account the geometric limitation of wheel penetration into the sleeper box due to the limited distance between adjacent sleepers.

Work [16] is aimed at predicting the behavior of a train after derailment. The process of interaction of wheelsets with crushed stone ballast is considered. The coefficient of rolling friction of the wheel on the ballast is determined. However, the interaction of the wheels with the sleepers and the influence of this interaction on the deceleration of the train is not considered.

From our review of the literature [3–16], it was found that the available methods and studies do not make it possible to estimate the amount of energy absorbed by the sleeper according to the parameters of the tracks left by the wheel of the railroad rolling stock when it derails.

3. The aim and objectives of the study

The purpose of this work is to determine the impact energy of a railroad wheel on a reinforced concrete sleeper when the wheelset derails according to the geometric parameters of the impact traces. This will make it possible to increase the accuracy of traction calculations of railroad rolling stock whose individual wheelsets move in the state of derailment along the rail-sleeper grid of a railroad track.

To achieve the specified goal, the following tasks must be performed:

– to devise a procedure for the theoretical assessment of energy when a wheel hits a reinforced concrete sleeper in the event of rolling stock derailment;

– to conduct experimental studies of the parameters of impact traces on reinforced concrete sleepers depending on the height of the center of mass of the striker above the place of impact on the sleeper;

– to conduct experimental studies of the effect of the location of the sleeper base on the geometric parameters of impact traces and the amount of impact energy;

– to derive the dependence of impact energy on the parameters of impact traces.

4. Research materials and methods

4. 1. Methodology of experimental studies of parameters of traces of wheel impacts into reinforced concrete sleepers and absorbed energy

The object of our research is reinforced concrete sleepers, which are subjected to the impact of the rolling stock wheel when the wheelset derails.

The research hypothesized that there is a certain type of relationship between the amount of energy absorbed by the sleeper when a railroad wheel rim strikes and one or more parameters of the track that remains on the sleeper as a result of the impact.

The following assumptions and simplifications were accepted as part of the data collection methodology:

– as a railroad wheel, a striker was used, the mass of which was less than the mass of the railroad wheel, and the equivalent energy of the impact was achieved due to the increased height of the fall;

– the presence of a connection between sleepers using a rail was not taken into account;

– studies were conducted only for one angle of impact, determined for the maximum possible drop of the wheel into the space between the sleepers.

An experimental study on determining the geometric parameters of impact traces on sleepers was carried out under laboratory conditions. Fifty test samples 0.5 m long were cut from the middle part of sleepers of type Sh-1-1 of one production series.

The research was carried out using the MK-30 pendulum hammer, the maximum impact energy of which, when using a standard striker, is 294 J. Given that when the wheel moves along the rail-sleeper grid, the sleepers are struck by the rim of the railroad wheel, the standard striker was modified – a part of the railroad wheel was attached in such a way that the impact on the sleeper occurs with the top of the rim (Fig. 2). At the same time, the weight of the experimental striker was 500 N.

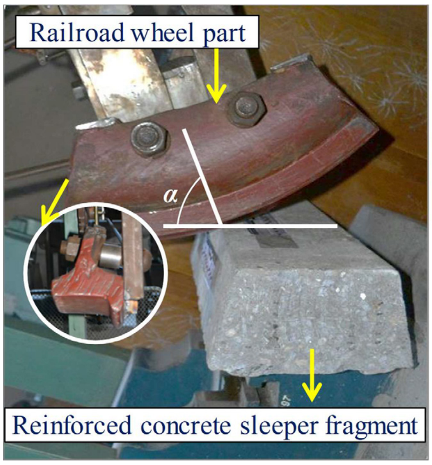


Fig. 2. Position of the test striker and sleeper at the moment of impact

Each test sample was mounted on a hammer rig on a solid base. Installation took place in such a way that its position and the position of the striker at the moment of impact coincided with the position of the wheel and sleeper when the wheel moved along the rail-sleeper grid at the average value of the angle α=1.179 rad.

The amount of energy E, which is absorbed by the sleeper when the striker strikes, will be:

$$E = Q \cdot H, \tag{1}$$

where Q is the weight of the experimental striker; H is the elevation height of the center of mass of the experimental striker above the point of impact.

At the maximum elevation height of the center of mass of the striker above the place of impact on the sleeper of 1.52 m, the maximum value of the impact energy absorbed by the sleeper was 760 J.

Each sample was subjected to impact three times. The height of the center of mass of the striker was 0.36 m at the first impact, 0.93 m at the second impact and 1.52 m at the third impact. At the same time, the amount of energy absorbed by the sleeper according to formula (1) was 180 J, 465 J, and 760 J, respectively.

4. 2. Schemes for determining the geometric parameters of impact traces on reinforced concrete sleepers

After conducting experimental tests, measurements of the following parameters of the trace after impact were performed: depth along the direction of force action h_t, length along the face of the sleeper l_t, maximum width along the top a_t and side face b_t of the sleeper. The appearance of impact traces and the scheme of their measurement are shown in Fig. 3.

Depth, width, and length were measured with a caliper.

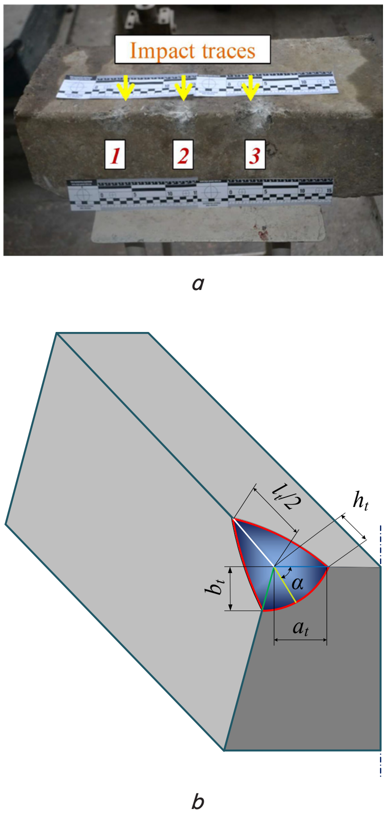


Fig. 3. Impact traces: *a* – appearance of impact traces; *b* – the scheme of impact trace measurements

5. Results of investigating the parameters of impact traces and energy when a wheel hits a reinforced concrete sleeper

5. 1. Methodology of theoretical assessment of energy when a wheel hits a reinforced concrete sleeper

A railroad wheel in the form of a solid metal non-deformable disk with radius R and weight Q, which is loaded with a force P, moves along a rail-sleeper grid with a distance between the sleeper axes l_s (Fig. 4). Sleepers in the plane of wheel movement are a trapezoid with height h and bases b and a. When moving, the wheel descends into the space between the sleepers by the amount h', while an impact occurs on the next sleeper. It is necessary to determine the range of values of the energy that is absorbed by the sleeper upon impact of the wheel, which descends from a height h'. This leads to the appearance of a trace on the sleeper, as well as the values of the angles α and γ depending on the values of l_s, b, a, and h.

The amount by which the center of the wheel is lowered can be determined from well-known geometric relationships according to the scheme in Fig. 4:

$$h' = R - \sqrt{R^2 - \frac{(l_s - b)^2}{4}}. \tag{2}$$

The angles α and γ are determined, respectively, from the formulas:

$$\alpha = \arccos\left(\frac{l_s - b}{2R}\right), \tag{3}$$

$$\gamma = \left(\frac{\pi}{2} - \operatorname{arctg}\left(\frac{a-b}{2h}\right)\right) + \arccos\left(\frac{l_s - b}{2R}\right). \tag{4}$$

The energy absorbed by the sleeper when lowering the wheel by an amount h':

$$E = (Q + P)h'. \tag{5}$$

In order to establish the range of values of the energy absorbed by the sleeper when a wheel with a radius R and weight Q loaded with an unsprung weight P hits it, calculations were performed according to formulas (2) to (5). The calculations were carried out for the limit values of the distance between the axes of the sleepers l_s, which are allowed in operation, and the dimensions of the upper base of the sleeper b, depending on its type.

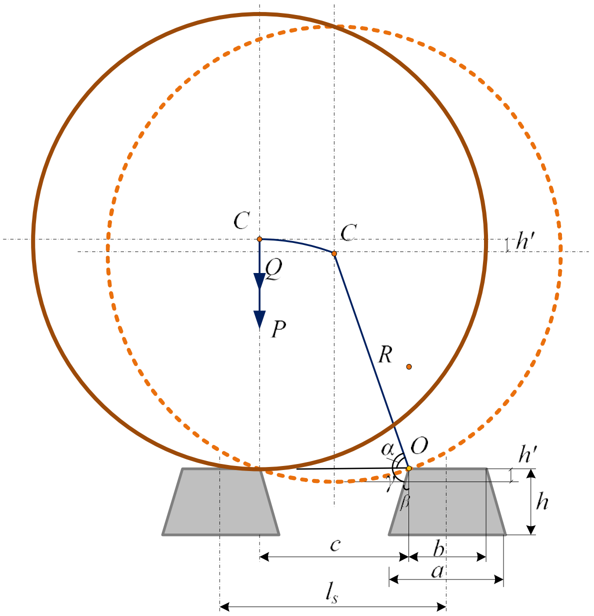


Fig. 4. Calculation scheme of the movement of a wheel along the rail-sleeper grid

For the calculation, we accepted R=0.503 m, which corresponds to the radius of the rail car wheel on the top of the rim, the weight of the wheel Q=5886 N. This corresponds to half the weight of the car wheelset, the unsprung weight P=3434 N, which corresponds to the total weight of the journal and half the weight of the side beam bogie of type 18–100. The results of the calculations are summarized in Table 1.

Table 1

Calculation results for the limit geometric parameters of the rail-sleeper grid

Initial data		Calculation results			
l_s, m	b, m	h'	α	γ	E, J
0.55	0.184	0.02546	1.251	2.582	237.3
0.625	0.174	0.05338	1.106	2.403	497.5

Table 1 shows that the amount of energy absorbed by the sleeper when a wheel of a car wheelset loaded with an unsprung weight hits it depends on the parameters of the rail-sleeper grid. The amount of energy is within E=237.3...497.5 J.

5. 2. Evaluation of geometric parameters of impact traces on reinforced concrete sleepers

During the experimental studies of the parameters of impact traces h_t, l_t, a_t, b_t, tests were carried out on fifty samples of reinforced concrete sleepers. The results of the average geometric parameters of impact traces are given in Table 2.

Table 2

Experimental data of the average geometric parameters of the trace after an impact

Sleeper No.	Point No.	H, m	h_t, mm	a_t, mm	b_t, mm	l_t, mm
1–10	1	0.36	7.84	18.7	26.3	35.2
	2	0.93	10.7	30.8	28.9	49.9
	3	1.52	12.83	38.0	33.9	57.4

The graphical dependence of the impact trace parameters on the height of the center of mass of the experimental striker above the impact site is shown in Fig. 5.

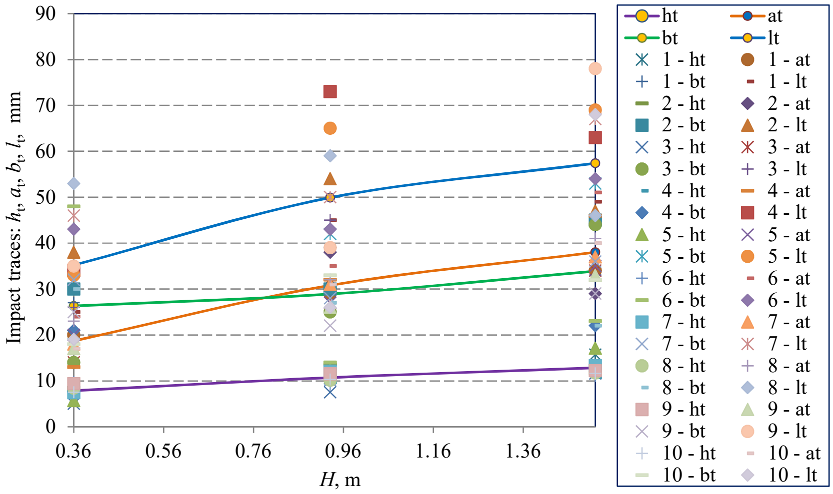


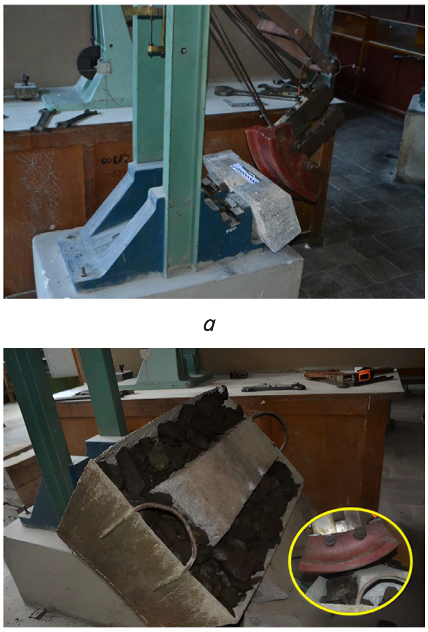
Fig. 5. Dependence of the parameters of impact traces h_t, l_t, a_t, b_t on H

The dependence of impact traces on the elevation height of the center of mass of the experimental striker above the place of impact into the reinforced concrete sleeper has a non-linear distribution. The magnitude of impact traces increases with the height of the striker. The parameters of the impact traces h_t, l_t, a_t, b_t depending on H are described by polynomials of the 2nd power with the approximation probability R^2=1.0.

5. 3. Studying the parameters of impact traces, taking into account the basis of the location of shapala

In order to determine the influence of elasticity of the ballast layer on the size of the trace that remains on the surface of the sleeper, two series of tests were conducted. In the first series, the sample was mounted rigidly on the hammer installation (Fig. 6, *a*). In the second series of tests, a metal box filled with ballast was installed on the hammer installation (Fig. 6, *b*). The box is filled with loosened ballast in compliance with the normative amount of backfilling of the sleeper box.

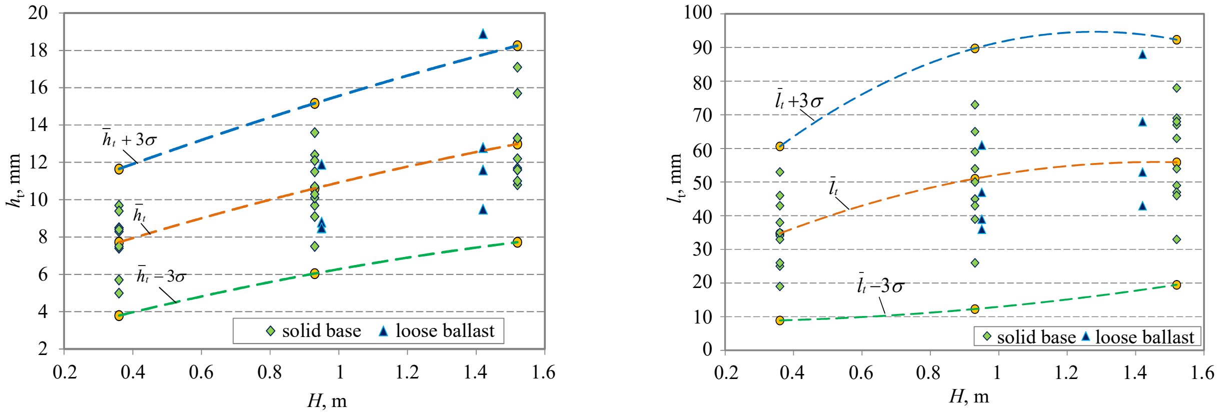
The height of the striker during the second series of tests was 0.95 m and 1.42 m. At the same time, the amount of energy absorbed by the sleeper together with the ballast was 475 J and 710 J, respectively.


a

b

Fig. 6. Testing reinforced concrete sleepers: *a* – on a solid rigid base; *b* – in a crushed stone box

For this series of tests, the shock trace parameters h_t and l_t were also determined. Experimental data from the first and second series of tests are illustrated in Fig. 7, which also shows dependences $\overline{y}=f(H)$, $\overline{y}+3\sigma=f(H)$, $\overline{y}-3\sigma=f(H)$.



a

b

Fig. 7. Experimental values of parameters h_t (a) and l_t (*b*) depending on the base of the location of a reinforced concrete sleeper: *a* – distribution of h_t values; *b* – distribution of l_t values

As can be seen from Fig. 7, installing the sleeper in loose ballast has no significant effect on the parameters of the trace that remains on the surface of the sleeper after impact. The experimental data obtained are within the limits of 3σ determined for the rigid support of the sleeper.

The nature of the location of the experimental data and dependences $\overline{y}=f(H)$, $\overline{y}+3\sigma=f(H)$, $\overline{y}-3\sigma=f(H)$ for the h_t and l_t parameters allows us to recommend the use of the value of energy absorbed by the sleeper parameter as an evaluation parameter h_t.

5. 4 Determining impact energy on a reinforced concrete sleeper based on the geometric parameters of impact traces

Fig. 8 shows a graphical representation of the dependence of energy of the impact on the sleeper on the height of the trace $E=f\left(\overline{h}_t\right)$, and Fig. 9 – the dependence of impact energy on the sleeper on the length of the trace $E=f\left(\overline{l}_t\right)$.

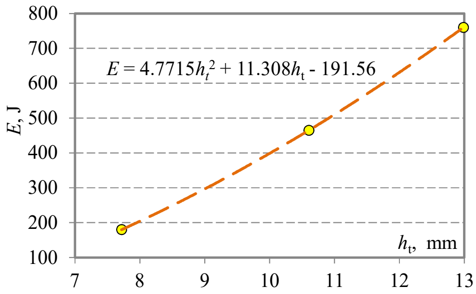


Fig. 8. Graphical dependence of impact energy in the sleeper E on h_t

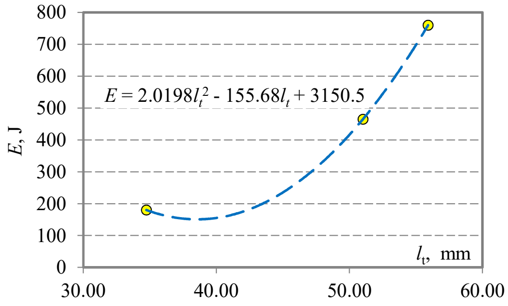


Fig. 9. Graphical dependence of impact energy in the sleeper E on l_t

The analytical form of dependence $E=f\left(\overline{h}_t\right)$ is described by a second-order polynomial according to relation (6), and $E=f\left(\overline{l}_t\right)$ – according to relation (7):

$$E=4.7715\cdot\overline{h}_t^{\,2}+11.308\cdot\overline{h}_t-191.56, \tag{6}$$

$$E=2.0198\cdot\overline{l}_t^{\,2}-155.68\cdot\overline{l}_t+3150.5. \tag{7}$$

The dependence $E=f(l_t)$ at point l_t=38.54 mm has an extremum, which does not allow recommending the parameter l_t for estimating the amount of absorbed energy for energy values E<200 J.

Thus, to determine the amount of energy absorbed by the reinforced concrete sleeper, it is recommended to use the parameter h_t – the depth of the trace left by the wheel rim in the sleeper, measured along the direction of impact. The calculated dependence is described by formula (6).

The obtained dependence allows determining the amount of energy absorbed by the sleeper according to the depth of the trace along the direction of impact of the rail wheel rim in the case of rolling stock derailment.

6. Discussion of results of assessing the energy of impact into a reinforced concrete sleeper according to the parameters of impact traces

The experiment conducted as part of the research differs from similar experiments, the results of which are reported in [13, 14], as follows:

– the spatial position of the striker was ensured, which corresponds to the actual spatial position of the railroad wheel at the time of impact on the sleeper, under the condition of the maximum possible drop (lowering) of the wheel between the sleepers according to the parameters of the rail sleeper grid;

– the striker was made from a part of a railroad wheel; its striking part was the rim of a real railroad car wheel;

– the experiment was carried out both with ballast and without ballast, which made it possible to determine the effect of ballast on the size of traces.

The research as a whole was not aimed at evaluating the strength characteristics of the sleepers but at determining the absorbed energy based on the results of the parameters of the impact trace and establishing the relationship between the depth of the trace and absorbed energy.

According to the improved methodology of theoretical assessment of energy when a wheel hits a reinforced concrete sleeper, it was established that the distance between the axes of the sleepers has a significant effect on the amount of energy when the wheel hits the sleeper. The amount of energy absorbed by the sleeper when a wheel of a car wheelset, loaded with unsprung weight falling on it, hits it is in the range of E=237...497 J, depending on the parameters of the rail-sleeper grid. At a distance between sleepers of 0.5 m, the amount of impact energy is 237 J, and at 0.625 m – 497 J.

The results of the experimental average statistical geometric parameters of impact traces obtained on fifty samples of reinforced concrete sleepers showed that the parameters of the trace h_t, l_t, a_t, b_t mm depend on the height of the striker H above the place of impact into the reinforced concrete sleeper. At the same time, the graphical dependences h_t, l_t, a_t, b_t on H have a non-linear nature of distribution (Fig. 5).

The results of experimental tests of the sleeper, when it was installed on a rigid hammer base and loose ballast (Fig. 7), showed that the base does not have a significant effect on the parameters of the impact trace. The obtained experimental values are within the limits of 3σ determined for the rigid abutment of the sleeper. Taking into account the fact that the ballast layer of the railroad track under operating conditions is compacted, and the sleepers and rails are connected to each other by rail fasteners, which increases the rigidity of the structure, the impact of ballast on the parameters of the track under real operating conditions will be even smaller and can be neglected.

Graphical dependences between the length of the face of the impact trace and the amount of absorbed energy (Fig. 9), as well as the depth along the direction of the force and the amount of absorbed energy (Fig. 8) are non-linear. The length of the impact trace has an extremum, which does not allow recommending this parameter for estimating the amount of absorbed energy for energy values E<200 J.

Therefore, it is recommended to use a parameter with a smaller spread of values as an assessment criterion for the amount of energy absorbed by a reinforced concrete sleeper. One of these parameters is the depth of the impact trace h_t.

One of the limitations of our research into the parameters of impact traces is the study of the geometric parameters of impact traces with a limited range of loads on a reinforced concrete sleeper. Namely, the height of the striker was 0.95 m and 1.42 m. At the same time, the amount of energy absorbed by the sleeper together with the ballast was 475 J and 710 J, respectively.

Among the shortcomings of our study of the parameters of impact traces is the failure to take into account the change in the impact energy from the geometric parameters of impact trace on the reinforced concrete sleeper, taking into account the change in the angle of application of the force during the impact.

Therefore, the further continuation of research work is the determination of the impact energy on a reinforced concrete sleeper, taking into account the type of rolling stock and the design of the railroad track superstructure. As well as the development of an algorithm for determining the additional resistance to the movement of railroad rolling stock based on the amount of absorbed energy.

7. Conclusions

1. A procedure for the theoretical assessment of energy when a wheel hits a reinforced concrete sleeper has been improved. As a result, it was found that the amount of energy absorbed by the sleeper when a wheel of a car wheelset loaded with an unsprung weight falling on it hits it is in the range of E=237...497 J depending on the parameters of the rail-sleeper grid.

2. Experimental studies of the geometric parameters of impact traces on reinforced concrete sleepers, depending on the height of the center of mass of the striker above the place of impact in the sleeper, showed that they have a non-linear distribution. At a height of H=0.36 m, the impact traces are: h_t=7.84 mm, a_t=18.7 mm, b_t=26.3 mm, and l_t=35.2 mm, respectively; at H=0.93 m: h_t=10.7 mm, a_t=30.8 mm, b_t=28.9 mm and l_t=49.9 mm; and at H=1.52 m: h_t=12.83 mm, a_t=38.0 mm, b_t=33.9 mm and l_t=57.4 mm.

3. The results of experimental tests of impact traces depending on the rigidity of the base of the reinforced concrete sleeper showed that the installation of the sleeper in loose ballast does not have a significant effect on the parameters of the trace that remains on the surface of the sleeper after the impact. The obtained experimental data are within the limits of 3σ determined for rigid sleeper support.

4. Analytical dependences of the amount of energy absorbed by the sleeper on the depth of the impact trace and the length of the trace along the face of the sleeper were found. It is recommended to determine the amount of energy absorbed by the sleeper to use the parameter of the depth of the impact trace, left by the wheel rim in the sleeper, measured along the direction of the impact. This will make it possible to determine in practice the amount of energy absorbed by the reinforced concrete sleeper by the depth of the track along the direction of the impact of the rim of a car railroad wheel when the rolling stock derails.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study and the results reported in this paper.

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Data availability

The manuscript has associated data in the data warehouse.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the presented work.

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