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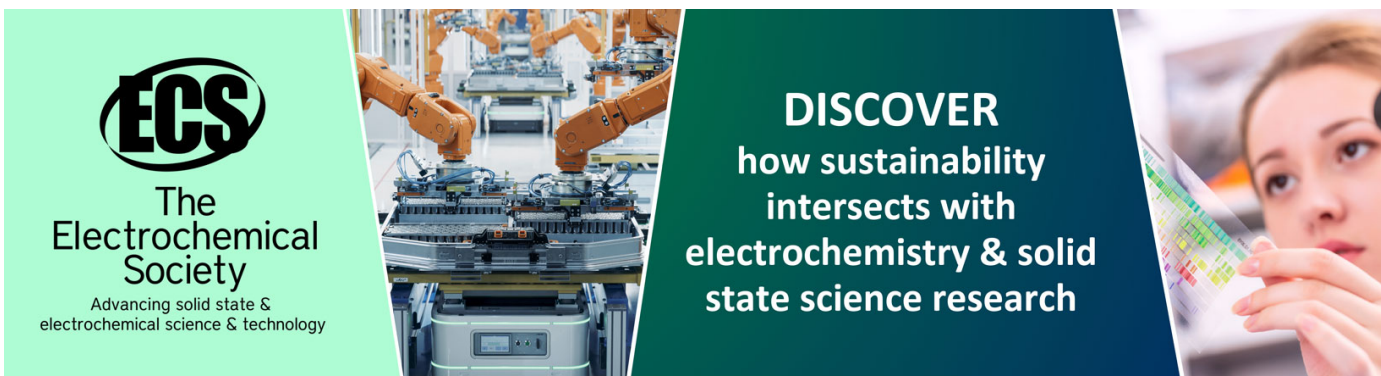
## Research of the calculation scheme for the brake lever transmission and construction of the load model for the brake pads of freight cars

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# Research of the calculation scheme for the brake lever transmission and construction of the load model for the brake pads of freight cars

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**Abstract.** In the article, the points of load application effecting the pads and other parts of the freight car three-element bogie during braking is considered theoretically using the example of the 2D diagram of the brake rigging. The special differences between the operating conditions of the first and second triangles of the car brake rigging and their effect on the wear of the pads when the train is moving without braking are described. The different operating conditions of the triangles are described to establish a causal relationship regarding the abnormal wear of the brake pads of the three-element bogies. For the first time, a calculation algorithm of a more accurate approach to theoretical calculations was proposed to determine the actual pressing forces in the brake pads on the wheels of the bogies. It proves the existence of the theoretical error, which is now inherent to the design models of freight cars brake rigging elements. The obtained algorithmic equations will help assess the wear of the brake pads and its effect on the stress-strain state in order to guarantee the railway traffic safety during the relevant theoretical and practical studies.

## 1. Introduction

The rolling stock, as well as other technical means, must operate smoothly and guarantee traffic safety, especially during braking, in order to ensure timely transportation. Therefore, the brakes belong to the main components of the modern rolling stock. The train traffic safety, as well as the traffic and carrying capacity of the railway depend to a large extent on their level of design perfection, efficiency, reliability and trouble-free operation. The technical and economic indicators of the use of freight cars of Ukrzaliznytsya JSC demonstrate that for the last 25 years, the brake systems of freight trains have become the most vulnerable parts in modern operating conditions and their condition in most of the cars is currently unsatisfactory. Therefore, Ukrzaliznytsya JSC together with the leading railway transport institutions work on increasing the durability and reliability of brakes of freight trains.

## 2. Analysis of recent studies and publications

The deteriorated performance of brakes of the rolling stock is directly related to the uneven wear of brake pads which occurs in many freight cars. A considerable amount of research is devoted to the causes and consequences of this adverse phenomenon. In particular, [1] presents the device used in brake rigging (BR) of bogies for the retraction of pads with automatic adjustment of their mutual position relative to the rolling surfaces of the wheels. However, importantly, such a device complicates the design of the bogie BR and requires systematic labour-intensive adjustments during the operation, and thus its use is not reasonable.



The authors in [2] present the results of comparative tests of various types of brake pads by Ukrainian and foreign manufacturers in the freight car bogies. Experimental tests of the pads with inserts by the domestic manufacturer and brake pads made in the US confirmed their ability to reduce the number of defects on the rolling surface of wheels. However, it should be noted that the existing design and operation of BR of the freight car bogie will contribute to the formation of abnormal wear in any types of brake pads.

The specific features of the creation of an original innovative BR design of the bogie (mod. ZK1) were presented by Chinese researchers in [3]. In this BR, the triangle in the bogie is fastened directly to the lateral frames in which for this purpose the cast guide brackets are provided, however this solution has significant disadvantages. The reliability of these cast guide brackets under varying load in the non-spring parts of the bogie impacting from the braking system will be lower than the general reliability of the lateral frames. In the points of contact of the pin of the triangles with the lateral frame, fatigue cracks may occur, which implies a threat to the traffic safety.

In the analyzed foreign studies [4], the analysis of some typical block brakes is highlighted that are rationally used in the rolling stock of the Chinese metro. The benefits of some of them include flexible operation, quick response and compact structure. Block brakes are used in some countries in the freight cars bogies to provide more effective braking and even wear of brake pads. However, the use of such brake blocks in freight car bogies will increase their weight, braking air consumption, maintenance time and the labour-intensity of repair of the car as a whole.

In [5], the stresses and temperatures occurring in the brake pad were analyzed using SolidWorks software and an alternative solution is proposed to improve the brake pad material and increase the service life.

In [6], the authors refer to a variety of frictional brake devices used for mechanical braking. It is noted that the frictional brake mechanisms in which the brake pads are used have adverse effect on the rolling surface of the wheels, since high temperatures occur in the “pad/wheel” friction zone, so the disc brakes are preferable.

Foreign scientists focus on the research of disk brakes, strength calculations of their elements, observations of their operation, are also on calculations of temperature regimes of some brake system elements of the rolling stock [7, 8]. When a train is braked with frictional brakes, thermal energy occurs in the contact area of tribotechnical bodies which dissipates by forced convection, conductivity and radiation from the open surfaces of the brake. In [9, 10] it is noted that overheating of the tribotechnical pairs can cause a malfunction of the braking system and prevent safe movement. In this connection, considerable theoretical work is done to increase the temperature during braking for various speeds and brake disc designs.

The analysis of foreign literary sources suggests that the problems of abnormal wear of brake pads, which are used in brake systems of three-element bogies, has not been given sufficient consideration.

### **3. The purpose of the article**

The purpose of this article is developing a theoretical hybrid computational model of the brake rigging with the determination of the pressing forces of the pads on the wheels to prevent their abnormal wear in the freight car three-element bogies.

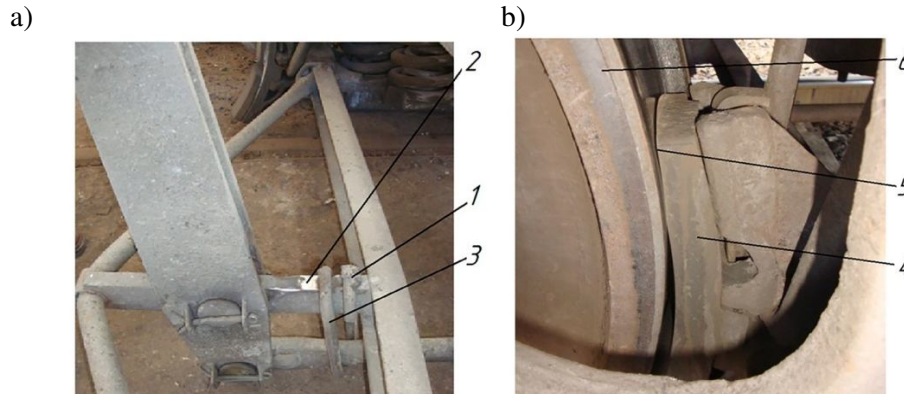
The following tasks should be addressed to achieve the set purpose:

- analyzing the state of the issue concerning the existing computational model of the brake rigging;
- determining adequate assumptions during developing a hybrid computational model for determining the pressing forces on wheels on freight car three-element bogies during braking;
- proposing a new approach for the methodological assessment of theoretical calculations for the determination of the actual pressing forces of the brake pads on the wheels of the three-element bogies at the final phase of braking of the freight car.

### **4. Presentation of the main material of the article**

It has been established that the BR design does not provide even distribution of the pressing forces of the brake pads on the wheels. The reason is that when the train is moving without braking, the upper edges of the pads are pressed to the rolling surfaces of the wheels and provide harmful friction with

the formation of distorted abnormal (double) frictional wear of the working body of the brake pads. Figure 1, a shows the typical damage to lock 1, and wear of brake strut 2 in contact with loop 3 of a typical even wear device for pads which causes the inclination of brake pad 1 (Figure 1, b) up to the stop and formation of wear of its top 5 in the wheel when the brakes are retracted.



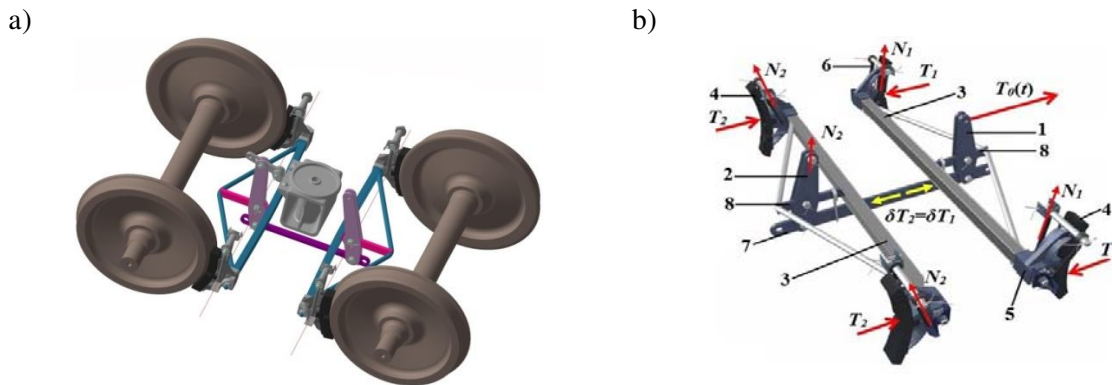
**Figure 1.** Typical appearance during the operation: a) – damaged typical even wear device for pads; b) – inclined and pressed top of the brake pad to the rolling surface of the wheel; 1 – destroyed lock; 2 – wear of the brake strut; 3 – hinge; 4 – break pad; 5 – wear of the top of the pad; 6 – wheel

To solve the problem of abnormal wear of the pads in the braking system of the freight car three-element bogies, the task is to achieve the elimination of the damaging moment of forces which arises as a result of imbalance of the BR elements. Therefore, a diagram of the spatial BR model of the freight car bogie is given (Figure 2, a), which we (conventionally) divide into two parts and assign them to the first and second wheel pair. Next, we will develop an allocation pattern of external and partially internal forces acting on the corresponding BR elements of the bogie during braking (Figure 2, b).

One of the parts (right) includes suspension triangle No. 1, with leading vertical lever 1 and other parts of the BR. External braking force  $T_0(t)$  of infinite power from the pneumatic brake system is transmitted through driving vertical lever 1 to triangle No. 1, which, with its brake shoes, presses the wheels of the first wheel to brake them. Thus, the first driving vertical lever (under yet unspecified conditions) is balanced with two reactions from the action of pressing forces on the wheels  $T_1$ , with the action of internal force  $\partial T_1$ , which, due to an excessive degree of freedom of the bogie BR, cannot be found by the conventional force method [11], as well as two forces  $N_1$  acting on the pendulum suspensions of triangle No. 1 with brake shoes and pads.

The second wheel pair includes triangle No. 2, vertical driven lever 2, on which a still indefinite part of force  $T_0(t)$  is transmitted through the bracing of both vertical levers which has the same magnitude, but opposite direction to internal force  $\partial T_2$ . In turn, this force is counterbalanced by two reactions  $T_2$  from the pad pressing onto the wheels during braking of the second wheel pair, by two suspension forces  $N_2$  of triangle No. 2 with shoes and brake pads and by the force arising in the attachment of the vertical lever during the "dead point" of the truck bolster sprung with elastic bogie sets, which are elements of the central suspension of the car.

Therefore, to develop a hybrid computational BR model, it is assumed that triangle No. 2 has an absolutely rigid rod, which is suspended at the ends by two hinged movable supports to the lateral frame of the bogie, so that its end parts interact with the pendulum suspensions at the ends of which shoes with brake pads are suspended, as in the case of suspension triangle No. 1 (forces  $N_2$  are similar to forces  $N_1$ ). However, in the centre of the rod it is attached to the brake strut and a string which form triangle No. 2 attached vertically by lever 2 to the "dead point" as to a kind of pivotal hinge support (reaction  $N_3$  acts in the middle of the truck bolster). Since the truck bolster has the appropriate degrees of freedom of displacement, it generally participates in linear oscillations (vertical dynamics) and in the angular lateral roll of the car. These fluctuations will not be taken into account at the first stage of the study.



**Figure 2.** General view: a) – spatial model of brake ragging in a three-element freight car bogie; b) – braking force transmission diagram  $T_0(t)$  without accounting to the gravitational forces: 1 and 2 – vertical levers; 3 – triangle; 4 – brake pad; 5 – brake shoe; 6 – pendulum suspension; 7 – bracing of vertical levers; 8 – brake strut;  $N_1(X_1, Z_1)$  and  $N_2(X_2, Z_2)$  – forces in pendulum suspensions of triangles (external);  $T_1$  and  $T_2$  – external braking reactions;  $\partial T_2 = \partial T_1$  – spreading internal "virtual" forces

To clarify the principle of operation of triangle BRs it is reasonable only to analyze the effects of force factors, without regard to the weight (mass) of all its elements, and assume that forces  $N_3 = N_2$ , which are evenly distributed over the beam of triangle No. 2.

Figure 2, b and 3 show that when the brake pads press on the wheels of each of the two wheel pairs, corresponding forces of reactions  $T_1$  and  $T_2$  occur in their contact areas.

For the determined object (BR design), the effect of all internal forces is not yet taken into account. Naturally, mass parameters of the chains are easy to take into account in analyzing the operation of the inertial GB.

In order to correlate the studies with the known simplified calculations of 2D diagrams of BG during braking of three-element bogies, we shall assume that two reactions  $N_1$  on both suspension sides of triangle No. 1 are equal, as well as three reactions  $N_2$  in a 2D rod model are equal (Figure 3), where the action of third force  $N_2$  of the attachment in the middle of the truck bolster during the "dead point" of the triangles by vertical driven lever 2 is added. Here we hypothetically assume the presence of connecting axis  $O_2-O_2$  which is projected onto the XOZ plane in one point  $O_2$  together with point  $O_3$ .

In accordance with the rules of theoretical mechanics, the components of force vectors  $N_1(X_1, Z_1)$  and  $N_2(X_2, Z_2)$  are projected to the coordinate axes  $Ox$  and  $Oz$ , so that their reactions, like in all BR elements, are directed along the rods:  $N_1^2 = (X_1^2 + Z_1^2)$ ;  $N_2^2 = (X_2^2 + Z_2^2)$  [12].

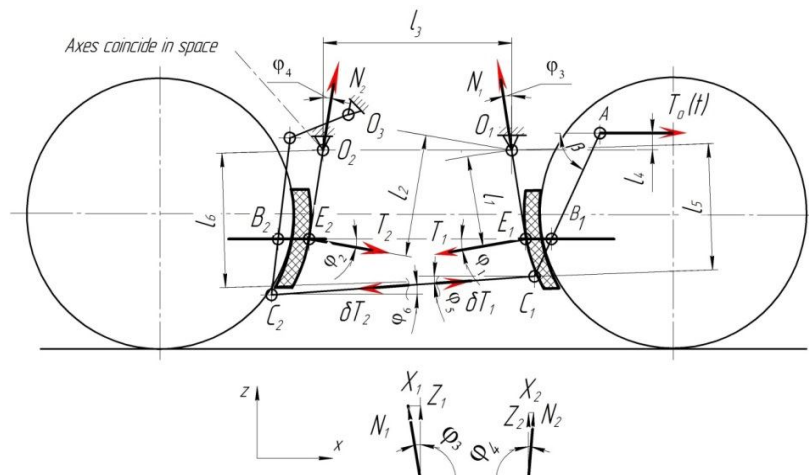
In view of this, we will write the equation of the static equilibrium of the kinematic chain of the bogie BR for the wheel pairs braked with the pads which are in the brake shoes, attached to the triangles and suspended through the pendulum suspensions to the lateral frames, and in particular, triangle No. 2 is additionally attached with vertical driven lever 2 to the "dead point" of the truck bolster of the freight car bogie:

$$\sum M_{O_1} = T_1 l_1 - T_2 l_2 + Z_2 l_3 + T_0 l_4 = 0, \tag{1}$$

$$\sum M_{O_2} = T_1 l_2 - T_2 l_1 + Z_1 l_3 + T_0 l_4 = 0, \tag{2}$$

$$\sum X = X_1 + X_2 + T_0 - T_1 \cos \varphi_1 + T_2 \cos \varphi_2 = 0, \tag{3}$$

where  $X_1 = -2N_1 \sin \varphi_3$ , and  $X_2 = 3N_2 \sin \varphi_4$ ;  $l_1, l_2, l_3, l_4, \varphi_1, \varphi_2, \varphi_3, \varphi_4$  – geometric and trigonometric parameters of the plan of positions of the BR chain system (Figure 3).



**Figure 3.** 2D diagram of BR during loading of the inertia-free bogie elements

In other words:

$Z_1 = -2N_1 \cos \varphi_3$  – projection of force  $N_1$  to axis  $Oz$ ;  $Z_2 = 3N_2 \cos \varphi_4$  – projection of force  $N_2$  to axis  $Oz$ .

Taking the values of  $X_1$  i  $X_2$  в (1), (2), (3) and taking into account forces  $N_1$  and  $N_2$  we obtain the equation:

$$\sum M_{O_1} = T_1 l_1 - T_2 l_2 + 3N_2 \cos \varphi_4 l_3 + T_0 l_4 = 0. \tag{4}$$

$$\sum M_{O_2} = T_1 l_2 - T_2 l_1 - 2N_1 \cos \varphi_3 l_3 + T_0 l_4 = 0. \tag{5}$$

$$\sum X = -2N_1 \sin \varphi_3 + 3N_2 \sin \varphi_4 + T_0 - T_1 \cos \varphi_1 + T_2 \cos \varphi_2 = 0. \tag{6}$$

The indefinite system of 3 algebraic equations (4), (5) and (6) has 4 unknown scalars of forces  $T_1, T_2, N_1, N_2$ . To supplement these equations by the fourth equation, which is essential for analysis of the effect of force factors using the level crossing method [11, 12], we divide the design of the bogie with a BR into two parts, as mentioned above.

We take into account the well-known axiom of mechanics: "If the entire system is in equilibrium, then any part of it (that is, any half) is also in a state of equilibrium" and also the fact that  $\delta T_1 \equiv \delta T_2 = \delta T$ . Let us consider the equilibrium of each of the two parts of this construction. Then we obtain the following equations separately for the right sides (Figure 4):

$$\sum X = 0; T_0 + \delta T - N_1 \cos(90^\circ - \varphi_1) - T_1 \cos \varphi_1 = 0; \tag{7}$$

$$\sum Y = 0; N_1 \sin(90^\circ - \varphi_1) - T_1 \sin \varphi_1 = 0; \tag{8}$$

$$\sum M_B = 0; T_0 \cdot l_{B_1 C_1} \cdot \sin \beta + \delta T \cdot l_{B_1 C_1} \cdot \sin \beta - M_0 = 0, \tag{9}$$

where  $M_0$  – compensating moment, which is formed by pushing the pad on the wheel and is  $M_0 = T_0 \cdot l_{AC_1} \cdot \sin \beta$ ,  $l_{B_1 C_1}$  – geometric parameter of the plan of positions of the BR chain system are shown in Table 1.





**Table 1.** Geometric data for calculations and systematization according to the data of the working drawings

Symbol	Value, [mm]	Value, [m]	Correspondence with the drawing
$l_1$	320	0.32	Distance from the line of action of force $T_1$ to point $O_1$ and $O_2$ .
$l_2$	434.1	0.4341	Distance from the line of action of force $T_2$ to point $O_1$ and $O_2$ .
$l_3$	680	0.68	Distance between points $O_1$ and $O_2$ is the arm for projections $Z_1$ and $Z_2$ , relative to points $O_1$ and $O_2$
$l_4$	612	0.0612	Distance from the line of action of force $T_0$ до т. $O_1$ and $O_2$ .
$l_5$	450	0.45	Distance from the line of action of force $\delta T_1$ to point $O_1$ .
$l_6$	480	0.48	Distance from the line of action of force $\delta T_2$ to point $O_2$ .
$l_{B_1C_1}$	160	0.16	Distance from the line of action of force $\delta T$ to point B.
$\varphi_1$	$10^0$	$\cos\varphi_1 = 0.984$	$\sin\varphi_1 = 0.1736$
$\varphi_2$	$10^0$	$\cos\varphi_2 = 0.984$	$\sin\varphi_2 = 0.1736$
$\varphi_3$	$10^0$	$\cos\varphi_3 = 0.984$	$\sin\varphi_3 = 0.1736$
$\varphi_4$	$10^0$	$\cos\varphi_4 = 0.984$	$\sin\varphi_4 = 0.1736$
$\varphi_5$	$3^058' = 3.97^0$	$\cos\varphi_5 = 0.997$	Angle of slope of force $\delta T_1$ to axis x
$\varphi_6$	$3^058' = 3.97^0$	$\cos\varphi_6 = 0.997$	Angle of slope of force $\delta T_2$ to axis x

**5. Control example**

The last frame of the animation plan of the BR positions during braking (at the final phase) of the freight car bogie mod. 18-100. All the necessary inputs for the resulting solutions (11) are given in Table 1. The sought-for force factors acting in the component elements of BR of three-element bogies are found using Mathcad software (Table 2).

**Table 2.** Comparison of desired forces acting in BR elements

Model for which the calculation is performed	$T_1$ , [kN]	$T_2$ , [kN]	$N_1$ , [kN]	$N_2$ , [kN]
Typical	46.0	46.0	-	-
Hybrid	45,53	45,53	8,03	8,03
Computational error, %	1.02	1,02	-	-

**6. Conclusions**

The following conclusions can be drawn on the basis of the conducted studies:

1. It is proved that the well-known 2D computational models of brake rigging of the three-element freight car bogie do not take into account the specific features and operation of triangles No. 1 and No. 2 during braking of the freight car.

2. The adequate assumption is determined in the development of the hybrid computational model of the brake rigging for determining the pressing forces of the pads on the wheels of the three-element



freight car bogie.

3. For the first time, a more accurate approach is proposed for the methodological assessment of theoretical calculations for determination of the actual pressing forces of the brake pads on the wheels to prevent their abnormal wear in the three-element bogies, which proves the existence of a theoretical error of 5-19% of the value that is now inherent to the design models of brake rigging elements of freight cars.

4. The obtained results will be further used for solving the problems related to the abnormal wear of the brake pads in the three-element freight car bogies.

## References

- [1] Radzihovskiy A A, Omelyanenko I A, Timoshina L A 2009 Ustroystvo otvoda tormoznykh kolodok *Vagonnyy park* **11-12** 18-21
- [2] Muradyan L A, Shaposhnik V YU, Vinstrot B U 2015 Ispytaniya perspektivnykh tormoznykh kolodok na zheleznykh dorogah Ukrainy *Lokomotiv-inform* **7-8** 20-22
- [3] Blohin E P, Alpyisbaev K T, Panasenko V Ya 2012 Telezhki ZK1 poluvagonov, postroennykh v KNR *Vagonnyy park* **9(66)** 12-14
- [4] Zhang Y, Zhang M 2018 The application status of unit brakes on metro vehicles in China *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)* **3 (15)** 17-23. DOI: 10.9790/1684-1503031723
- [5] Ambikaprasad O Chaubey, Abhijeet A Raut 2015 Failure Analysis of Brake Shoe in Indian Railway Wagon *IPASJ International Journal of Mechanical Engineering* **3 (10)** 37-41
- [6] Sharma R C, Dhingra M, Pathak R K 2015 Braking systems in railway vehicles. *International Journal of Engineering Research & Technology (IJERT)* **4** 206-211
- [7] Gupta V, Saini K, Garg A K, Krishan G and Parkash O 2016 Comparative Analysis of Disc Brake Model for Different Materials Investigated Under Tragic Situations *Asian Review of Mechanical Engineering* **5 (1)** 18-23
- [8] Sarip S 2013 Design Development of Lightweight Disc Brake for Regenerative Braking – Finite Element Analysis *International Journal of Applied Physics and Mathematics* **3 (1)** 52-58
- [9] Day A J 1979 A finite element approach to drum brake analysis *Proceedings of the Institution of Mechanical Engineers 1847-1982* **193** 401-406
- [10] Day A J 1991 Drum brake interface pressure distributions *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering 1989-1996* **205** 127-136
- [11] Hubska V V, Kryshtal V F 2018 Kinematyka tverdoho tila ta dynamika tochky. Konspekt lektsii *Kyiv: Natsionalnyi tekhnichnyi universytet Ukrainy "Kyivskiy politekhnichnyi instytut im. Ihoria Sikorskoho"*. pp. 75 – 99
- [12] Shpachuk V P, Pushnia V O, Rubanenko O I, Harbuz A O 2016 Teoretychna mekhanika. Konspekt lektsii *Kharkiv: KhNUMH im. A. M. Beketova* pp. 117 – 137
- [13] Instrukciya z remontu ghaljmivnogho obladnannja vagoniv 2004 TsV – TsL – 0013 *Kyiv: TOV "Vydavnychi dim "SAM"*
- [14] Fomin O, Lovska A, Masliyev V, Tsymbaliuk A, Burlutski O 2019 Determining strength indicators for the bearing structure of a covered wagon's body made from round pipes when transported by a railroad ferry *Eastern-European Journal of Enterprise Technologies* **7 1 (97)** 33–40. doi: 10.15587/1729-4061.2019.154282
- [15] Instruksiia z ekspluatatsii halm rukhomoho skladu na zaliznytsiakh Ukrainy 2004 TsT – TsV – TsL – 0015 *Kyiv: TOV "NVP Polihrafservis"*