UDC 62-529
DOI: 10.15587/2312-8372.2018.127930

Mel'nick V.,
Karachun V.,
Shybetskij V.,
Fesenko S.,
Shafarenko N.

REDUCTION OF TECHNOLOGICAL RISKS IN SUBWAY AND RAIL TRANSPORT

У роботі поставлена задача забезпечення гарантованої безпеки перевозу пасажирів в поїздах метрополітену. За об'єкт проведених авторами досліджень обрано процес взаємодії прибуваючого з великою швидкістю на станцію електропотягу метрополітену з пасажиром, що нерухомо очікує, або, який переміщується до краю платформи внаслідок штовханини тісної маси пасажирів. Показано, що значне тертя поверхні підборів взуття пасажира та тертя верхньої частини тіла о бічну поверхню вагона обмежують можливість переміщення людини в просторі. Таким чином, в найпростішому випадку, верхня частина і кінцівки ніг будуть формувати нерухому ось обертання. Але потужний удар цю ось здеформує і направить таким чином, що вона буде рухатися по поверхні, що є сукупністю миттєво обертальних рухів. І, таким чином, миттєва ось обертання описує конічну поверхню з вершиною, співпадаючою з підборами взуття.

Виявлено, що жорстко пов'язавши з людиною систему координат xyz можна визначити три кути Ейлера повороту відносно миттєвої осі і побудувати таблицю напрямних косинусів, які дозволяють визначити кінематичні характеристики примусового тіла людини відносно осей, зв'язаних з ним – $\omega_x \omega_y \omega_z$.

Результати макетних досліджень підтвердили думку стосовно доцільності заміни поступального руху бічної поверхні вагона на складний рух, додатково обладнаної на бічній поверхні вагона огороджувальної стрічки безпеки. Ця стрічка рухається в протилежний до напрямку вагона бік, але з тією за величиною швидкістю. Синтез цих двох рухів дає ефект появи нерухомої частини стрічки безпеки відносно пасажира, що стоїть на платформі, і, отже, максимально підносить певність і надійність перевезення пасажирів електропоїздами підземки.

Лабораторний макет повністю підтвердив прогнозуємий ефект відсутності небезпеки травмування пасажирів і ступінь присутності технологічного ризику в експлуатаційних умовах.

Ключові слова: *стрічка безпеки, потяг метрополітену, технологічні ризики, обернений фізичний маятник.*

1. Introduction

It is difficult to imagine a person's real life in big cities without the services of the «subway» and railway transport. Metropolitan can be called without exaggeration the most popular form of transport in Kyiv (Ukraine).

For a day, the metropolitan subway carries up to 1.5 million passengers. For the majority of Kyivans, it remains the fastest and most reliable way to get to this or that point of the city. However, in terms of convenience and security, the Ukrainian subway slightly loses to its counterparts from more developed countries. The most loaded, at present, is Lisova station (Kyiv, Ukraine).

In Kyiv, cases of people falling on rails are not rare – be it an attempt at suicide or an accident. When this happens, the movement of the train stops along the entire line, many are late for work, huge crowds accumulate at the stations, which then flow into the carriages. In the Tokyo Metro (Japan), along the platform are installed special fences, which prevent people from falling onto the rails.

At the entrance to the platform apron and at the exit from it is necessary to be careful with the glass doors that open in both directions. A rush of air or due to the negligence of the person walking, it is possible to injure the limbs of the hands and head.

The greatest danger for passengers on the platform is the train arriving at the station, which moves powerfully at high speed. When the train comes to the station, it drives so much air in front of you, the «wind» on the apron begins even before you see the fire of the train in the tunnel to your right.

Thus, there is a significant technological risk of railway technology that is due to casual clutches of the passenger clothing surface on the edge of the platform with the side surface of the car body. A special danger occurs during peak hours, when the station is oversaturated by passengers and there is a danger of congestion at the edge of the platform (Fig. 1). This can lead to a forced collision of a person with the high-speed side of the car. Also, the next step is pulling the person under the wheels into the platform gap. This is due to the considerable adhesion of the moving surface of the person's clothing to the moving surface of the car body, as well as the fixed heels of the person's shoes with the platform surface.

According to the official information of the Moscow subway, today, on all overloaded lines, the minimum possible interval is reached, which is 1.5 minutes. To make it even less impossible – this is dangerous, since it can lead to accidents.

By 2017 in the Kyiv subway there were 18 cases of people falling on rails. Two people were killed. In 2017 half a billion passengers took advantage of the Kyiv subway.

Fig. 1. Congestion during peak hours on the subway platforms

As it is known, the infrastructure of the stations does not change. The old branches of the subway – the so-called «Typical column stations of the XX century» in the next 20 years, will not be rebuilt [1]. And the number of people on the platform will constantly increase. This, in the end, will provoke a constant congestion on the platform of the subway. All this will lead to injuries or accidents. And the precautions that now exist – it will not be enough, namely:

- rules of conduct in the subway;
- restrictive yellow bands on the apron floor (Fig. 2);
- a loud beep of the train, which informs about the arrival of the train on the platform.

Fig. 2. Yellow warning strips

All this usually leads to the thought of the need to apply new methods and technologies on the platforms of the subway and the railway.

In the world practice, new measures of protection began to be applied when arriving at the subway train, where high-speed trains operated at a speed of 100 km/h are used. These are closed subway stations (also called horizontal lift and double-door stations) in St. Petersburg (Russia), The Beijing Subway (China) [2]. The disadvantages of such protection approaches are: a sharp restriction of the capacity of the entire line, the need for a more precise stop on the doors, parking at the station increases by 15–20 seconds.

One of such promising areas of passenger protection on the platform apron may be a «warning strips», which will create a buffer zone between the subway car and the passenger. Thus, the possibility of a collision between the passenger and the side of the subway car that quickly moves (speed from 60–80 km/h) will be eliminated. All this will eliminate the twisting of the motionless person on the platform and pulling it under the wheels.

The fixed passenger on the platform will have before his eyes instead of the movable side surface of the car body a fixed surface of the warning stripe and, thus, the technological risk of the train is eliminated.

The urgency of research, of course, is invention of such technical solutions, in which technological risk on an underground overpass, that is, a subway system, would be minimized.

2. The object of research and its technological audit

The object of research is the process of occurrence and development of technological risks of transportation of passengers on transport.

A powerful moving coupler in the subway car appears at the station with great speed, carries a great risk of injuring passengers, due to inattention and the accumulation of a large number of people, especially with oversized things, causing congestion at the edge of the platform. Congestion, as a rule, leads to touching the passengers of the surface of the car. The significant friction of the heels of the man's shoes with the platform surface and the impact of the car on the upper limbs of the person are the cause of the forced rotation of the body around the fixed point – the heels of the shoes. If add to this the man's attempts to stay and not fall, there is an additional movement of the upper and lower extremities, which not only change the moment of inertia relative to the instantaneous axis of rotation, but push the neighbors on the apron, causing confusion of passengers. This phenomenon is especially dangerous during rush hours and at stations that connect with the railway and large enterprises, where there is a significant mass of people. Thus, the large number of possible displacements of each of the passengers forms the unpredictable state of a large mass of people and serves as a direct danger not only to injuries, but also to people's lives.

One of the most problematic places is the need to ensure the maximum equality of the speed of the mobile (car body) movement and the relative motion (warning strips). Finally, it is necessary to ensure that the navigation map is unconditionally aligned with the direction of movement of the warning stripe relative to the car when the exit to the apron changes to the other side of the train.

3. The aim and objectives of research

The aim of research is reducing the technological risks of transporting passenger traffic in urban and rail transport.

The objectives of research are as follows:

1. To carry out an analysis of the occurrence mechanism of phenomena that creates the danger of injuring passengers on a platform in anticipation of a train.
2. To construct computational models for the occurrence of technological risks in passenger transport under operating conditions.
3. To present the technical implementation of eliminating the causes of the danger of injuring passengers in anticipation of arriving (or departing) railway transport on the passenger platform of an underground or overland road.

4. Research of existing solutions of the problem

More and more attention is paid to safety issues, due to the growth of the speed of electric trains and the density of traffic in the railway transport and in the subway, in particular, in the large cities of many countries. A large number of passenger traffic forces railway workers to seek new ways of providing technical security for traffic, in particular, reducing the traumatizing of passengers or other accidents.

It is currently known technical measures in the form of physical barriers (PSD), which are not able, in full, to protect passengers from attempts to commit suicide [3]. Assessment of the degree of probability of suicide accidents allows to evaluate the effectiveness of the means, on the one hand, and determine the most dangerous parts of the subway [4]. At the stage of search for the means of artificial separation according to some principles (age data, sex, etc.) to determine the effectiveness of a particular remedy. This principle will also allow to assess the degree of locality of the crowd on the crowded apron [5]. The issue of the concept of mass passenger traffic in the context of the security problem and proposals for measures to prevent and respond to such phenomena is considered in [6]. Considering the compatibility and simplicity of the Microsoft Access 2010 software, the Shanghai authorities use it to comprehensively and carefully design the incident database with the MOID subway base [7]. For the purpose of early warning of risks and an increase in the level of safety management in the subway, the dispatching fault log management and analysis database system (DFLMIS) is proposed, which contains almost all types of accidents that occurred during Metro operation [8].

Identification of risks is an important task in managing the risks of subway and underground transport. To this end, a security risk identification system (SRIS) has been established for the safety of the movement of subway trains to control and early warning of dynamic risks [9]. The process of dynamic route optimization and passenger flow control and dynamic optimization task, which minimizes deviations from the schedule, and maximizes traffic safety in the aisles along subway lines is given in [10]. Simulation and laboratory tests of the influence of pedestrian traffic control on boarding and disembarking passengers at subway stations are carried out. The research is carried out with the help of a foot simulator (studio LEGION) and experiments in the laboratory of dynamic human studies (HDL) of the University of Los Angeles in Santiago de Chile. Criteria are obtained for the management of pedestrian traffic on the platform and the subway door [11]. In [12] the main data are given regarding the progress in the management of the safety of underground equipment in China over the past decade, namely:

– establishment of laws and regulations for the management of safety risks of underground equipment;
– implementation of a security management plan;
– creation of a decision support system for risk management and early warning based on information technology;
– strengthening the study on safety management, forecasting and prevention.

5. Methods of research

The proposed technical solution eliminates the danger of injuring passengers on high-speed electric transport of the subway and railway and can be used to combat technological risks in transport.

The well-known construction of the electric-train car ER 2 (Russia), which contains an all-welded load-bearing body, which side, end walls and a roof is lined with a steel corrugated sheet. The cabin of the car is equipped with a ventilation system with two ventilation units installed in the end parts in the attic rooms of the vestibules. The exterior walls of the body are made with corrugations. The side walls of the body on each side have four slots for the equipment of sliding doors [13]. The drawbacks of this technical solution for the electric train cars are the high degree of danger for passengers waiting for the train on the apron, especially for those that are near the edge of the platform.

Also known is the construction of a serial intermediate subway car 81-714.5 (USSR) in the form of an all-welded construction with a bearing body made in the form of a closed shell reinforced by longitudinal and transverse beams. The car body has cutouts in the side walls under the doors and windows, and in the roof under the outdoor air fences [14].

The disadvantage of this technical solution is the increased danger from the high-speed train for passengers on the platform, more precisely, when the train enters the station and when leaving the station. A special danger occurs during peak hours. At this time the station is oversaturated by passengers and there is a danger of crushing at the edge of the platform. This can lead to a forced collision of a person with the high-speed side of the car. It is also possible for this pulling the person under the wheels due to the considerable adhesion of the surface of the person's clothing to the surface of the car body.

The basis of the technical solution is the task of ensuring the guaranteed safety of passengers traveling on subway trains. A man collides with the moving side surface of the car during his rapid arrival at the station, or acceleration on departure, using warning strips. This stripe is installed on the outer sides of the cars with forced forward movement in the opposite direction of the train and at the same speed.

The proposed technical solution of the subway car with external warning stripe contains the undercarriage, the body of the all-welded bearing structure. The body is made in the form of a closed shell with cutouts in the side walls under the windows and doors, as well as in the roof of the car for ventilation equipment of the passenger compartment. The ventilation equipment consists of devices for intake of outside air, its distribution of exhaust air from the car. The lower parts of the outer sides of the car, below the window, are equipped with warning stripes with forced forward motion in the opposite direction of the train movement and at the same speed.

Warning stripe with forced forward motion in the opposite direction of the train and with the same speed carries out two movements. Regarding the station platform – the portable forward movement together with the body of the car and the relative translational motion along the side surface of the car in the opposite direction of the train. Synthesis of these two movements builds a fixed state of the surface of the stripe relative to the platform and, accordingly, its stationary state relative to the passengers that are there. All the same, as when braking the train, and for its acceleration.

Fig. 3 is a general view of the proposed technical solution of the subway car with an external warning stripe.

Fig. 4 shows the top view of car in Fig. 1.

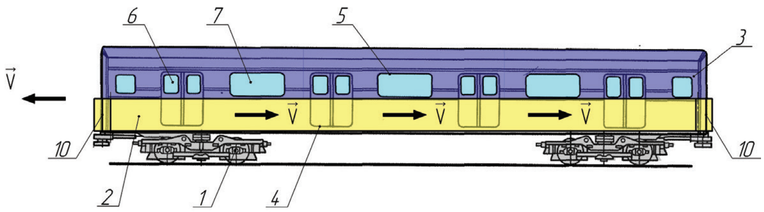

Fig. 3. Subway car with external warning stripe

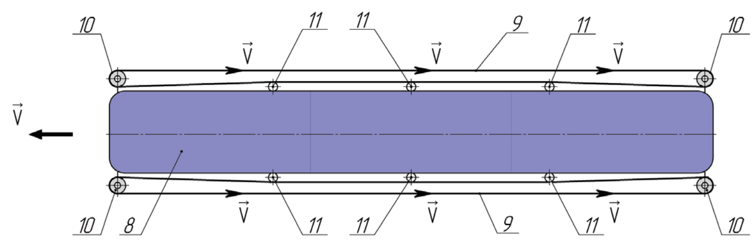

Fig. 4. Top view of the subway car

Fig. 5 shows the design of the rolls.

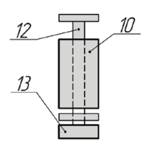

Fig. 5. Design of the rolls

The proposed technical solution of the subway car with an external warning stripe (Fig. 3) is aimed at achieving a guaranteed safety of passengers traveling on subway trains. The construction contains chassis 1, body 2, consisting of side walls 3 with door 4 and window 5 slots under doors 6 and windows 7, roof 8, warning stripe 9 (Fig. 4). Rolls 10 secure the warning stripe, and rolls 11 are responsible for controlling the stripe tension. The rolls 10 have guides 12 for lowering and lifting the warning stripe 9, at the ends of the guides 12 are friction disks 13 of the same diameter as the rolls 10 (Fig. 5).

The powerful high-speed entrance of the subway electric train from the tunnel to the station is an extremely high risk for passengers on the platform, it does not have fences from its edge. Significant congestion of passengers on the edge of the platform, coupled with insufficient vigilance of the situation on the rails of the railway overpass, creates the danger of a sudden touch of a person with the shoulder or limbs of the hands. This occurs as a result of a powerful impact from the side of the car of a rapidly approaching subway train, which leads to forced rotation of the person around its longitudinal axis of the trunk. The degree of this impact is determined, first of all, by the force of the impact of the train and by the considerable friction of the passenger's clothes in the walls of the car and by the great force of grafting at the location of the fixed heels of the person's shoes with the surface of the platform, which is quite natural. The latter factor allows to confirm the presence, in this case, of the spherical movement of the passenger's body relative to the heels of the footwear of the lower extremities. A person, sensing the impact and impact of the car, naturally places the extremities of the upper arms with his things, showing unconditioned reflexes to keep the body in a position of equilibrium, but thereby, complicating his dynamic state even worse after an impact. In the future, it is difficult to predict, but the statistics give definite conclusions regarding the fact that the upper limbs serve as the capture of the upper body car and the tearing of the lower part of the human body from the platform. This will inevitably involve a person in the gap between the edge of the platform and the surface of the car.

The work of the proposed technical solution of the subway car with external warning stripe is carried out as follows. On the runway, warning stripe 9 is in the upper position, to the level of the window sill. When approaching the station, the friction discs 13 engage with the vertical edge of the passenger platform and begin to rotate together with the rolls 10 around the guides 12 at an angular speed:

$$\omega = \frac{V}{R},$$

where V – train speed; R – radius of the friction disk 13. As a result of the rotation, the forward movement of the warning stripe is provided with the speed:

$$V_1 = \omega R = \frac{V}{R} \cdot R = V,$$

opposite the speed of the car body. Thus, relative to the person standing motionless on the edge of the platform, stripe 9, it is understandable, does not move, because its state is determined by the synthesis of two translational movements – the transfer and the relative. Transfer movement is the translational movement of the car, relative – also the progressive movement of the stripe, but with respect to the side surface of the car and in the opposite direction at a speed equal to the value of the transfer speed. When the train departs from the station, the dynamics of the phenomenon practically repeats.

When the train stops at the station, the automation (for example, electric or pneumatic) lowers the rolls 10 with the stripe down, giving access to the door. The doors open and passengers enter and exit the cabin. Then the doors close, the automation again raises the rolls with the warning stripe up and the train starts to move from the station to the line. Then everything repeats itself.

A heavy flexible warning stripe, for example, made of rubberized fabric, preserves the original stiffness for the entire lifetime. Thus, the proposed technical solution of the subway car with an external warning stripe will ensure the guaranteed safety of transportation of passengers on subway trains and significantly reduce the likelihood of a violation of the schedule of the underground railway.

6. Research results

With the purpose of practical confirmation of theoretical reasoning, the operating model of the subway train is constructed, equipped with a warning stripe (Fig. 6).

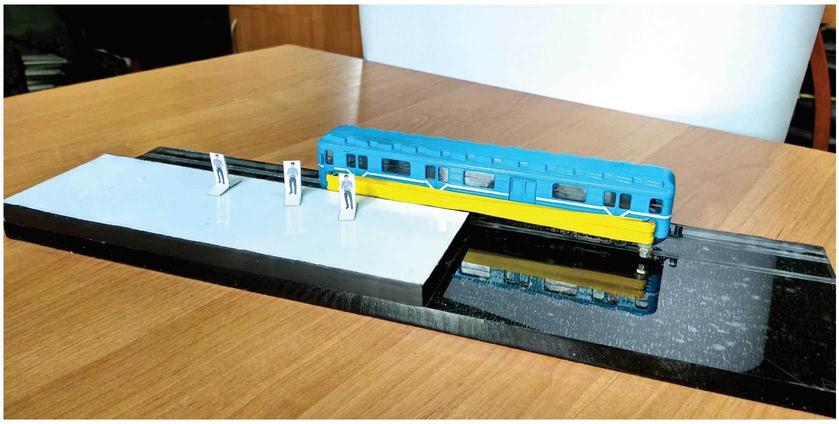

Fig. 6. Laboratory model of the subway car with external warning stripe

Laboratory studies of the model allow to state with the greatest degree of certainty the following:

– the forced spherical movement of the human body as a result of a powerful lateral impact by the surface of the car and the subsequent capture of it due to the considerable friction of the heels of the shoes on the surface of the platform and the friction of the clothes of the person in the side surface of the car forces the person to move. This resembles the motion of an inverse spherical pendulum with a fixed point on the heels of a person's shoes. What is the natural result of the synthesis of three rotational movements, which are determined by the three Euler angles. The peculiarity of the computational model is that in this context, the fundamental interpretation of the investigated phenomenon is realized. At the same time, the great influence on the development of the danger of interaction between the car and the person, and sometimes decisive, carries out the behavior not only of the passenger himself. Important behavior also surrounding, about standing passengers, not only from the point of view of the dynamics of interaction between the car and the person. And a number of other conditions, for example, the psychological state of individuals and the possibility of occurrence of panic among a significant number of people in a small area of the station of an underground overpass;

– the synthesis of three rotational movements around a fixed point of the heel surface of a person's shoes makes it possible to determine the instantaneous axis of rotation of a person, describes a conical surface whose vertex coincides with the fixed point of the heel of the shoe. The Euler angles ψ (precession angle), θ (nutation angle) and φ (proper rotation), with the help of the computed table of directing cosines will allow to automate the process of revealing the features of the spherical motion of a person and determine the conditions for the manifestation of local features of motion;

– studies of the laboratory model confirmed the effectiveness of replacing the translational motion of the lateral surface of the car with additional equipment by its flexible stripe that moves at the speed of the train, but in the opposite direction. Thus, the synthesis of two oppositely directed motions of the proposed stripe is artificially formed with the same speed. As a result, the stripe surface relative to the real passenger on the platform does not move.

The results of the model studies confirm the opinion about the expediency of replacing the translational motion of the side surface of the car with a complex movement, additionally equipped on the side surface of the car with a warning stripe. It moves in the opposite direction to the car side, but with the same speed. Synthesis of these two movements gives the effect of the appearance of a fixed part of the warning stripe with respect to the passenger standing on the platform and, therefore, maximizes the confidence and reliability of the passengers' transportation by electric trains of the subway.

The laboratory model completely confirms the predicted effect of the danger absence of injury to passengers and the degree of technological risk presence in operating conditions.

The technical solution does not limit the possibilities of automatic quality control of the proposed technical implementation.

7. SWOT analysis of research results

Strengths. The original side of the results of laboratory research is the confirmation of the theoretical prerequisites for eliminating the causes of the danger of injuring passengers in anticipation of an incoming train on the platform. This will ensure: protection from human traumatism; reduce the number of lawsuits; will reduce the number of hospital patients that may be due to injuries, avoid stopping the work of the subway station.

Weaknesses. The disadvantages of the proposed technical solution are the need to complement the car with devices and to regulate the speed of the warning stripe equal to the car speed.

Opportunities. Having advertising information on the warning stripe, it is possible to ensure the payback of this product in a year. Now 1 m^2 of advertisement costs about 72 USD. The warning stripe on only one car provides 80 m^2 of permanent advertising, rather than glued pamphlets inside the car, which can be broken at any moment. Also, the advertising of the painted subway system requires, in addition to paying for advertising, more expensive paint and time to ensure that the car dried up.

The warning stripe can be used not only in the subway and electric trains. This product is necessary for high-speed trams, funiculars, and especially will be important for cable cars in ski resorts.

Threats. The entrance to the subway platform at different stations is not necessarily one way. Thus, it is necessary to complete the composition of the navigation map. The effectiveness of the warning stripe depends, among other things, also on the preservation of its physical and mechanical properties – tension, elasticity, providing a dry contact surface with the passenger.

8. Conclusions

1. It is shown that a significant friction of the heel surface of the passenger's shoes and the friction of the upper part of the body in the side surface of the car limits the possibility of human movement in space. Thus, in the simplest case, the upper part and extremities of the legs will form a fixed axis of rotation. But, a powerful blow this deforms this axis and directs in such way that it will move over the surface, which is a collection of instantly rotational movements. And, thus, the instantaneous axis of rotation describes a conical surface with a vertex that coincides with the heels of the shoe.

2. It is revealed that by rigidly linking to a person a coordinate system xyz, it is possible to determine three rotation angles of the Euler relative to the instantaneous axis and to construct a table of directing cosines that make it possible to determine the kinematic characteristics of the forced human body relative to the axes associated with it – $\omega_x\omega_y\omega_z$.

3. It is shown that the warning stripe, which moves in the opposite direction to the car, but at the same speed, builds the synthesis of two movements directed at the same speed, but in different directions. This results in the instantaneous immovable state of the warning stripe element relative to the passenger. So, it is possible to conclude that the mutual real estate rights and stripe is a guarantee of the full danger of man.

References

1. Sbornaya stantsiya metropolitena kolonnogo tipa: A. s. 692938 USSR. MPK E02D 29/00, E21D 13/00 / Antonov O. Yu. et al.; Assignee: All-Union Scientific Research Institute of Transport Construction. Appl. No. 2321922/29-03; Filed: 02.02.1976; Published: 25.10.1979, Bull. No. 39.
2. Dvustvorchatye dveri razdvizhnogo tipa: A. s. 264665 USSR. MPK E05F 7/04 / Gutsko V. A. et al.; Assignee: Leningrad Branch of the State Design and Exploration Institute «Metrogiprotrans». Appl. No. 1204194/29-14; Filed: 19.12.1967; Published: 03.03.1970, Bull. No. 9.
3. The effectiveness of platform screen doors for the prevention of subway suicides in South Korea / Chung Y. W. et al. // Journal of Affective Disorders. 2016. Vol. 194. P. 80–83. doi:10.1016/j.jad.2016.01.026
4. Uittenbogaard A., Ceccato V. Temporal and spatial patterns of suicides in Stockholm's subway stations // Accident Analysis & Prevention. 2015. Vol. 81. P. 96–106. doi:10.1016/j.aap.2015.03.043
5. A novel approach for crowd video monitoring of subway platforms / Hu X. et al. // Optik – International Journal for Light and Electron Optics. 2013. Vol. 124, No. 22. P. 5301–5306. doi:10.1016/j.ijleo.2013.03.057
6. Yang J.-T. Safety Risk Analysis and Countermeasures Study on Regular Mass Passenger Flow of China's Urban Subway // Procedia Engineering. 2016. Vol. 135. P. 175–179. doi:10.1016/j.proeng.2016.01.104
7. An incident database for improving metro safety: The case of shanghai / Zhang X. et al. // Safety Science. 2016. Vol. 84. P. 88–96. doi:10.1016/j.ssci.2015.11.023
8. The safety management of urban rail transit based on operation fault log / Ding X. et al. // Safety Science. 2017. Vol. 94. P. 10–16. doi:10.1016/j.ssci.2016.12.015
9. Safety risk identification system for metro construction on the basis of construction drawings / Ding L. Y. et. al. // Automation in Construction. 2012. Vol. 27. P. 120–137. doi:10.1016/j.autcon.2012.05.010
10. Joint optimal train regulation and passenger flow control strategy for high-frequency metro lines / Li S. et al. // Transportation Research Part B: Methodological. 2017. Vol. 99. P. 113–137. doi:10.1016/j.trb.2017.01.010
11. Seriani S., Fernandez R. Pedestrian traffic management of boarding and alighting in metro stations // Transportation Research Part C: Emerging Technologies. 2015. Vol. 53. P. 76–92. doi:10.1016/j.trc.2015.02.003
12. Qian Q., Lin P. Safety risk management of underground engineering in China: Progress, challenges and strategies // Journal of Rock Mechanics and Geotechnical Engineering. 2016. Vol. 8, No. 4. P. 423–442. doi:10.1016/j.jrmge.2016.04.001
13. Vagony / ed. by Kuzmich L. D. Moscow: Mashinostroenie, 1978. 376 p.
14. Posobie po ekspluatatsii vagonov metropolitena modeley 81-717,5 i 81-714,5. Moscow: Transport, 1993. 447 p.

Mel'nick Viktorij, *Doctor of Technical Sciences, Professor, Head of the Department of Biotechnics and Engineering, National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute», Ukraine, e-mail: vmm71@i.ua, ORCID: http://orcid.org/0000-0002-0004-7218*

Karachun Volodimir, *Doctor of Technical Sciences, Professor, Department of Biotechnics and Engineering, National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute», Ukraine, e-mail: karachun11@i.ua, ORCID: http://orcid.org/0000-0002-6080-4102*

Shybetskyy Vladislav, *PhD, Senior Lecturer, Department of Biotechnics and Engineering, National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute», Ukraine, ORCID: http://orcid.org/0000-0001-5482-0838*

Fesenko Sergii, *Assistant, Department of Biotechnics and Engineering, National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute», Ukraine, ORCID: http://orcid.org/0000-0003-1001-0643*

Shafarenko Nikolai, *Lead Engineer, Department of Biotechnics and Engineering, National Technical University of Ukraine «Igor Sikorsky Kyiv Polytechnic Institute», Ukraine, e-mail: vmm71@i.ua, ORCID: http://orcid.org/0000-0001-9786-4574*