Simulation of an Emergency Collision of an Electric Locomotive with a Truck

Mikhail Vladimirovich Zhuykov[1,2], Alexander Eduardovich Pavlyukov[1], Konstantin Mikhailovich Kolyasov[1] and Daniil Vadimovich Duvanov[1,2]
[1]*Ural State University of Railway Transport, Yekaterinburg, Russia*
[2]*LLC Ural Locomotives, Verkhnyaya Pyshma, Russia*

Keywords: Emergency collision, electric freight locomotive, passive restraint system, finite element method, discrete element method, bulk cargo, kinetic energy absorption, deformation, acceleration.

Abstract. The article presents a real case of a collision of an electric locomotive with a truck that was transporting crushed stone, as a result of which it led to tragic consequences. Numerical modeling combined on the basis of the finite element method and the discrete element method made it possible to evaluate the effect of bulk cargo located at the time of collision in the back of a truck on irreversible deformations of the driver's cab, destruction of glazing, absorption of impact energy, as well as accelerations at the driver's seat installation places. The numerical modeling technique takes into account the geometric and physical nonlinearity of the object of study. Particles of bulk cargo are considered as solid bodies with unchangeable geometry. The deformation of the system occurs due to deformations at the points of contact between the particles. The results of the study can be used to make changes to the power frame of the driver's cab of operated electric locomotives in order to avoid tragic consequences and preserve the life and health of the locomotive crew.

1 INTRODUCTION

In the work (Krasyukov, 2020) and article (Krasyukov, 2014), the number of emergency collisions of railway rolling stock on public tracks for 2001 to 2008 inclusive is given, where it is indicated that more than 72% of all collisions occur at unguarded railway crossings, 10% at guarded railway crossings, 17% with wagons during shunting work, 1% – with other obstacles.

Collisions of railway transport with trucks happen very often. Trucks often transport crushed stone, sand or other bulk cargo, therefore, when an electric locomotive collides with trucks, not only material damage to the rolling stock can be caused, but also damage to the health of the locomotive crew, and sometimes injuries incompatible with life in the electric locomotive directly at the time of the collision.

A striking example of the above is the case of a collision that occurred on October 23, 2021 with a freight electric locomotive 3ES5K "Ermak" (Zapovednaya highway, https://zen.yandex.ru), as a result of which the driver's assistant died from his injuries, the consequences of the collision are shown in Fig. 1.

The above case shows that it is necessary to minimize the injury of the locomotive crew, as well as to exclude the death of the locomotive crew in case of emergency collisions of electric freight locomotives. Reducing injuries and eliminating the death of the locomotive crew is possible due to a workable passive restraint system used on newly produced freight electric locomotives, as well as in the modernization of driver's cabs on operated freight electric locomotives manufactured in the Russian Federation (RF).

The object of the study is the driver's cabin of an electric freight locomotive with glazing.

In this article, the authors conduct a study of the collision of an electric locomotive with a truck, in the body of which there is a bulk cargo, and evaluate deformations, energy intensity and longitudinal accelerations (in places where the driver's seats are installed) for the driver's cab of an electric locomotive based on numerical modeling in order to assess the performance of the passive restraint system.

In numerical modeling, the authors combine two methods: the finite element method and the discrete

Zhuykov, M., Pavlyukov, A., Kolyasov, K. and Duvanov, D.
Simulation of an Emergency Collision of an Electric Locomotive with a Truck.
DOI: 10.5220/0011582500003527
In *Proceedings of the 1st International Scientific and Practical Conference on Transport: Logistics, Construction, Maintenance, Management (TLC2M 2022)*, pages 253-259
ISBN: 978-989-758-606-4

(a) (b)

Figure 1: Consequences of the collision between 3ES5K (Ermak) electric locomotive and truck on October 23, 2021: (a) general view after the collision, (b) view of the cab of the electric locomotive after the collision.

element method. The combination of these methods makes it possible to assess the impact of bulk cargo located at the time of collision in the truck body on irreversible deformations of the driver's cab, destruction of glazing, absorption of impact energy, as well as accelerations at the driver's seat installation places.

2 MATERIALS AND METHODS

The main approaches and provisions to the concepts of passive restraint systems (PRS) for passenger trains of locomotive traction are considered in (Sobolevskaya, 2015; Tyrell, 2005). The main design solution of PRS for modern freight electric locomotives manufactured in the territory of the Russian Federation is presented in (Zhuykov, 2022).

The main design solution of PRS for modern freight electric locomotives manufactured in the territory of the Russian Federation is shown in Fig. 2.

The weakest point in the existing PRS is the driver's cab due to the fact that at the moment the current domestic standards do not take into account the variety of scenarios in emergency collisions, in contrast to European and American standards for crash tests, and, therefore, need to be improved.

The authors of this article for the study of an emergency collision took an obstacle in the form of a truck with the following dimensions: length 6600 mm (6.600 m), width 2500 mm (2.500 m), height 2975 mm (2.975 m). The weight of the truck is 24558 kg (24.558 tons), the weight of the bulk cargo is 22388 kg (22.388 tons), the weight of the electric locomotive is 200,000 kg (200 tons). The initial speed of the collision is 72 km/h (20 m/s).

The structure of the model of a two-section electric locomotive, shown in Fig. 3, for collision research based on numerical modeling consists of the following components: two bodies, four trolleys, two modular cabins, body-to-trolley connections, intersectional coupling, railway track, obstacle.

When setting the problem, initial conditions are set, it is assumed that the material of the electric locomotive is not deformed at the initial moment, all the components of the electric locomotive move at the same speed in the same direction. While all the rail nodes and obstacles are at rest. In addition, the

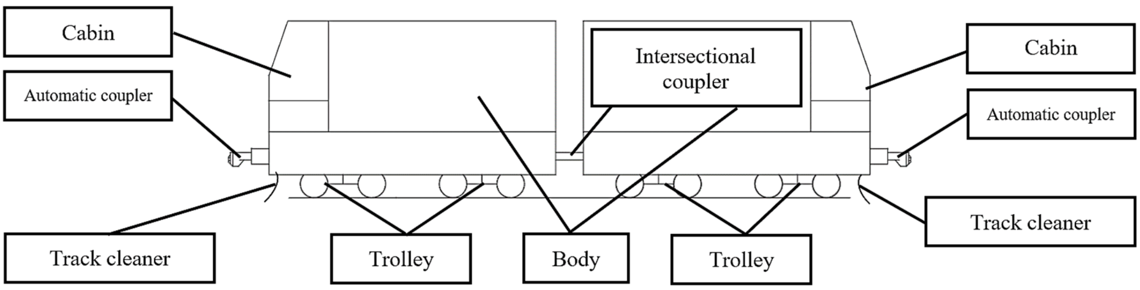

Figure 2: The main design solution of the PRS of modern domestic freight electric locomotives.

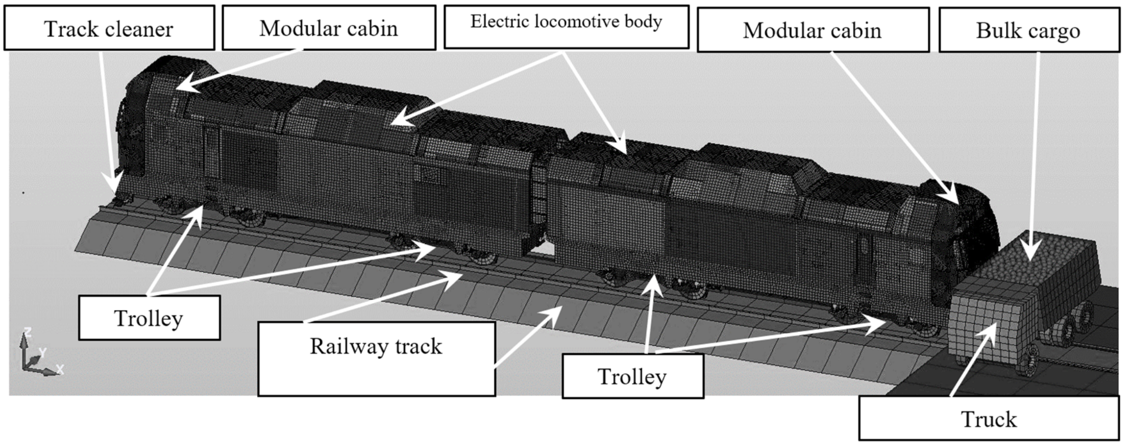

Figure 3: Structure of an electric locomotive model for collision study based on numerical simulation.

volumetric forces due to the acceleration of gravity are set.

To model the bulk cargo, the discrete element method was used, which was developed by Kandall in 1971 to analyze problems related to the rock mechanics.

Assumptions were used in the calculation (Larsson, 2014):

1. Particles are treated as solids with unchangeable geometry. The deformation of the system occurs due to deformations at the points of contact between the particles.
2. Particle-particle contact occurs at the points of contact.
3. A contact is used that allows a slight overlap at the contact points. The overlap is small compared to the particle size, movement and rotation of the particles.
4. Only at the points of contact is there any interaction between the particles. The time step is small enough, allowing only the force from the particle to its contact particles.
5. Newton's second law of motion is used to determine the motion of solid particles, acceleration and velocity are constant at each time step.
6. The time step allows the disturbance to propagate only to the nearest neighboring particle, the forces acting on the particle are determined only by the interaction with the contacting particles.

To study an emergency collision based on numerical simulation, the ANSYS 2022R1 calculation complex with the LS-DYNA R12.0 solver was used (Livermore Software Technology Corporation (LSTC), 2018; Livermore Software Technology Corporation (LSTC), 2018), the finite element method and the discrete element method with an explicit integration scheme were chosen, the geometric and physical nonlinearity of the object of study was taken into account. Shell finite elements were used for the body of the electric locomotive, modular cab, trolley frames, obstacles and rails; for wheelset axles - three-dimensional hexahedral finite elements; for the suspension of the chassis, one-dimensional finite elements were used, which allow simulating a linear elastic-dissipative connection between two nodes; and distributed mass elements for equipment, locomotive crew. The number of one-dimensional elements used was: beam – 72, spring and damper – 134; elements of distributed mass – 2; three-dimensional hexahedral finite elements - 2600; shell finite elements -289115; discrete elements - 227.

3 RESULTS AND DISCUSSION

In case of an emergency collision of an electric locomotive with a truck, in the body of which there is a bulk cargo, irreversible deformations of the driver's cab and the body of the electric locomotive occur. Irreversible deformations of the driver's cab and the electric locomotive body are shown in Fig. 4 (a), 4 (b), 4 (c), 4 (d) for four values of the physical collision time: 0.05 sec., 0.10 sec., 0.15 sec., 0.20 sec., respectively. The movement of bulk cargo when an electric locomotive collides with a truck is shown in Fig. 5 (a), 5(b), 5(c), 5 (d) for four values of the physical collision time: 0.05 sec., 0.10 sec., 0.15 sec., 0.20 sec., respectively.

As a result of the collision of an electric locomotive with a truck, in the body of which there was a bulk cargo, the glazing of the driver's cabin was

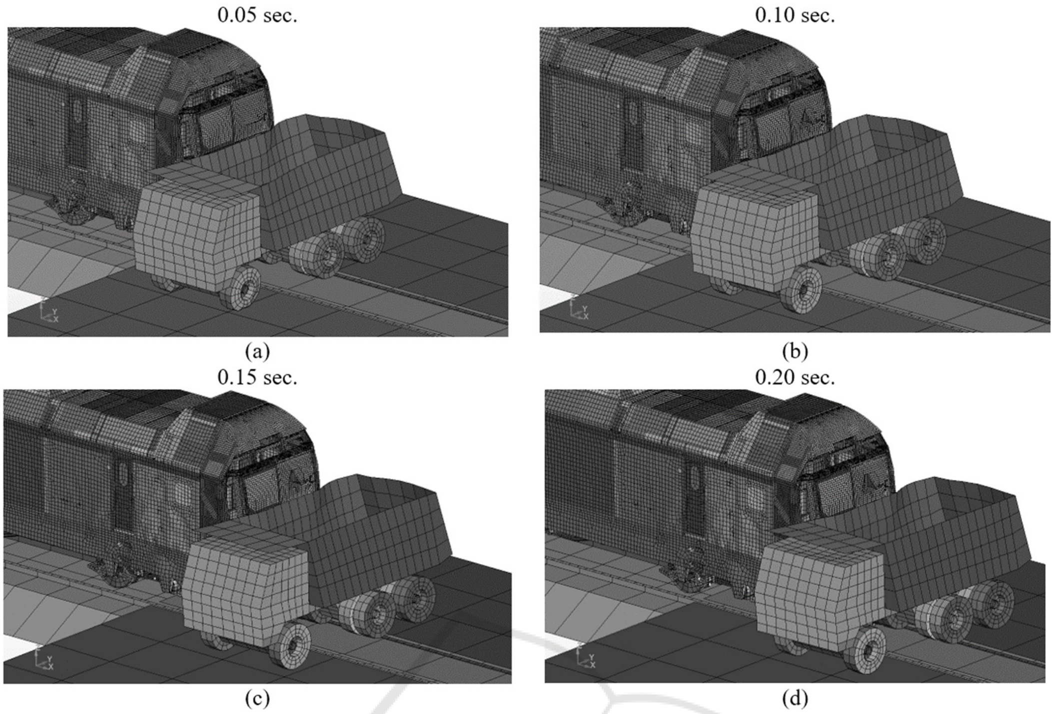

Figure 4: Study results: (a) irreversible deformations at a time of 0.05 seconds, (b) irreversible deformations at a time of 0.10 seconds, (c) irreversible deformations at a time of 0.15 seconds, (d) irreversible deformations at a time of 0.20 seconds.

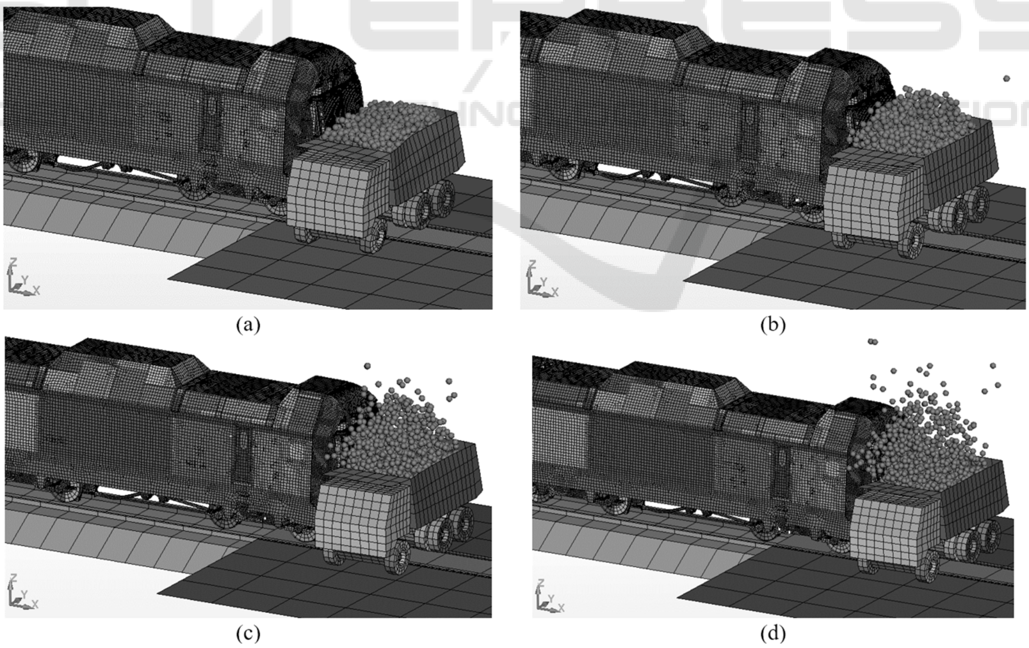

Figure 5: Study results: (a) movement of bulk cargo at a collision time of 0.05 seconds, (b) movement of bulk cargo at a collision time of 0.10 seconds, (c) movement of bulk cargo at a collision time of 0.15 seconds, (d) movement of bulk cargo at a collision time of 0.20 seconds.

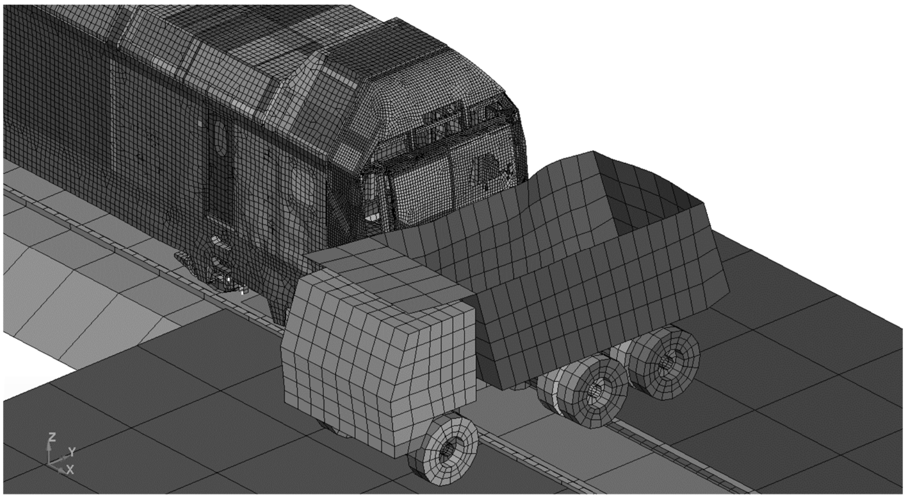

Figure 6: Destruction of the glazing of the driver's cab according to the simulation results at a collision time of 0.2 seconds.

destroyed from the side of the driver's assistant, visually shown in Fig. 6 at the time of the physical collision time of 0.20 seconds.

According to the results of numerical simulation of an emergency collision of an electric locomotive with a truck, in the body of which there is a bulk cargo, the dependences of kinetic energy absorption and accelerations in the places of installation of the driver's seats on time are obtained. The absorption of kinetic energy in an emergency when an electric locomotive collides with a truck without bulk cargo was 0.064 MJ, and with bulk cargo – 0.324 MJ.

The results of numerical simulation of an emergency collision showed that the power frame of the driver's cab meets the safety requirements, the vital space for the locomotive crew is preserved, the acceleration in the driver's seats did not exceed 75 m/s^2.

Graphs of absorbed kinetic energy are shown in Fig. 7 (a), accelerations at the driver's seat installation places in Fig. 7 (b) and in Table 1.

4 CONCLUSIONS

The authors of the article present a real case of a collision of an electric locomotive with a truck that was transporting crushed stone, as a result of which it led to tragic consequences.

The article presents a methodology for investigating an emergency collision of an electric freight locomotive based on numerical modeling, taking into account the geometric and physical nonlinearity of the object of study using the finite element method and the discrete element method.

The values of irreversible deformations, absorbed energy, accelerations in the places where the driver's seats are installed in an emergency collision are determined.

The application of the finite element method together with the discrete element method makes it possible to assess the destruction of the glazing of the driver's cab of an electric freight locomotive.

Table 1: Results of an emergency collision study based on numerical simulation of an emergency collision of an electric locomotive with a truck.

Type of collision	Without bulk cargo	With bulk cargo
Cabin deformation, mm	23.4	10,6
Absorption of kinetic energy, MJ	0.64	0.324
Acceleration at the places where the driver's seats are installed, m/s^2	59.42	73.95
Obstacle mass, tons	24.558	46.946
Initial collision speed, km/h	72	
The height of the upper point of the obstacle from the LRH, mm	3.370	2.900

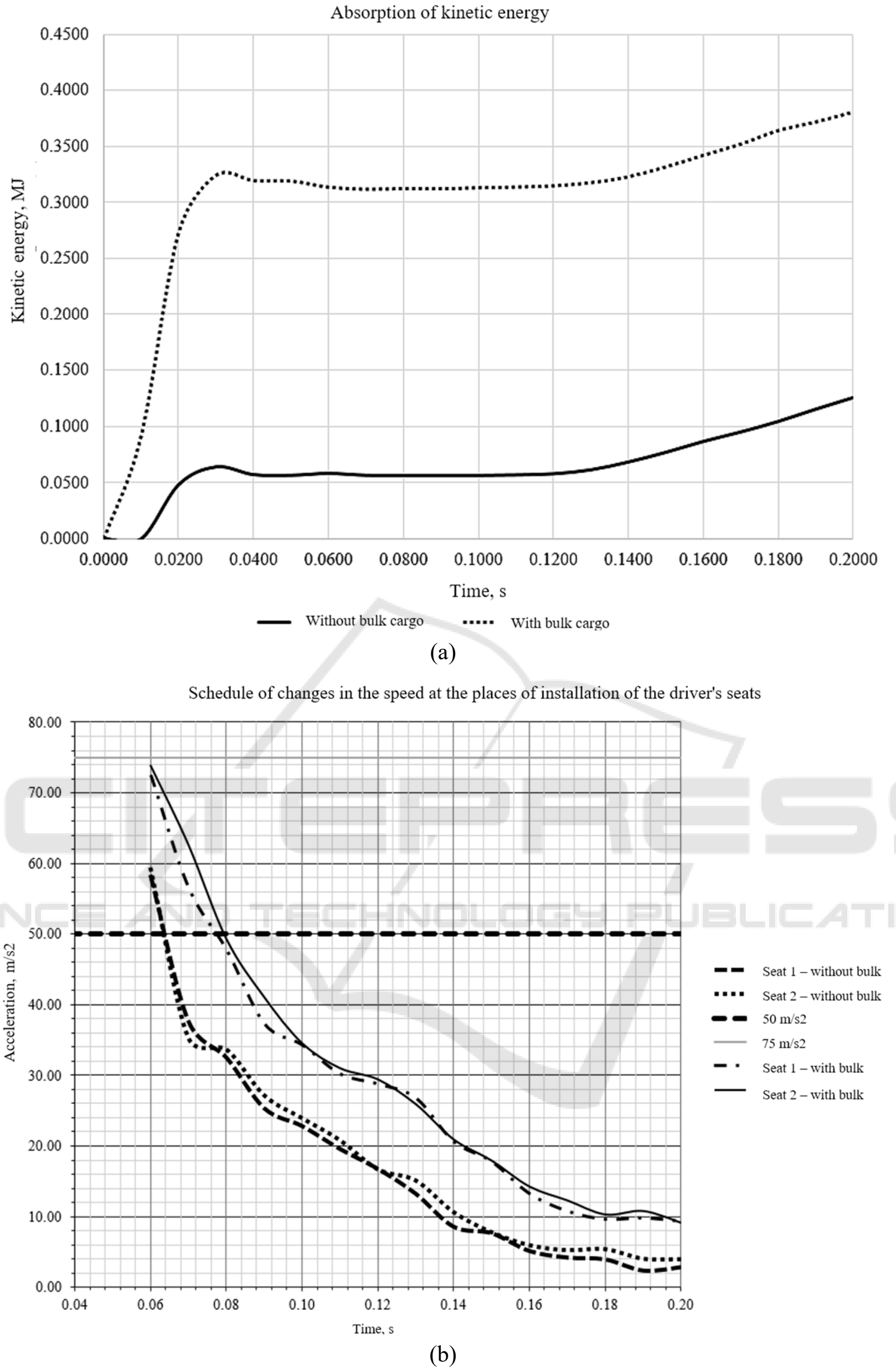

Figure 7: Study results: (a) absorbed kinetic energy, (b) accelerations in the places where the driver's seats are installed.

The results of the study can be used to improve drivers' cabins when modeling emergency collisions for electric locomotives of other series in operation, which require a reduction in irreversible deformations to preserve vital space for the survival of the locomotive crew and not exceed accelerations in the places where the driver's seats are installed 75 m/s ^{2}.

REFERENCES

Krasyukov, N. F., 2020. Simulation of the loading of the locomotive structure in the head-on collision with the obstacle on the railway track. Dissertation for the degree of Candidate of Technical Sciences: 05.22.07 – Railway rolling stock, train traction and electrification. p. 152.

Krasyukov, N. F., 2014. How to improve the passive restraint of rolling stock. *Lokomotiv.* 8. pp. 9-10.

Are crash tests of modern locomotives conducted as for cars and are there seat belts on them? Zapovednaya highway. https://zen.yandex.ru.

Sobolevskaya, M. B., Sirota, S. A., 2015. The main provisions of the concept of passive protection of the high-speed passenger train in case of emergency collisions. *Tech. Mechanics*. 1. pp. 84-96.

Tyrell, D. A., 2005. A Crush Zone Design for An Existing Passenger Rail Cab Car. *Proceedings of 2005 ASME International Mechanical Engineering Congress & Exposition November 5-11, Orlando, Florida. IMECE2005-82769.* pp. 1-10.

Zhuykov, M., Pavlyukov, A., Kolyasov, K., Duvanov, D., 2022. Study of Deformations and Energy Intensity of the Driver's Cabin of a Freight Electric Locomotive during Emergency Collisions based on Numerical Simulation. AIPCP. 1. pp. 1-10.

Larsson S., 2014. Characterization and modeling of rock impact on steel plates. 27th June 2014. Lulea University of Technology. Department of Engineering Sciences and Mathematics. Division of Mechanics of Solid Materials.

Livermore Software Technology Corporation (LSTC). 2018. The book. «*LS-DYNA Keyword User's Manual, Volume I*». p. 3186.

Livermore Software Technology Corporation (LSTC). 2018. The book. «*LS-DYNA Keyword User's Manual, Volume II*». p. 1613.