

CAD/CAE-technologies application for assessment of passenger safety on railway transport in emergency

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Abstract. A possibility of using current software products realizing CAD/CAE-technologies for the assessment of passenger safety in emergency cases on railway transport has been analyzed. On the basis of the developed solid computer model of an anthropometric dummy, the authors carried out an analysis of possible levels of passenger injury during accident collision of a train with an obstacle.

1. Introduction

A progressive development of railway industry in Russia is connected with the organization of speed and high-speed passenger communication. At that a rolling-stock used must meet the increased requirements for safety and comfort of passenger traffic. Along with the increase of competitive ability of railways in the field of passenger traffic, a likelihood of emergency connected with collisions of trains with obstacles increases. The considerable dynamic loads arising during collisions and affecting rolling-stock bodies result in their destruction and also in heavy injuries of passengers and members of train crews. At that injuries may be of different kinds – from light injury up to a fatal outcome.

In emergency situations the passengers fall from their berths to the floor, tables and other interior things and also get injured because of a luggage drop upon them. But the majority of body injuries of various degrees of severity is connected with the secondary collisions of passengers and train personnel with parts of internal equipment including that torn from bolting.

According to the degree of severity, personal injuries obtained within the cars may belong to: severe injuries – in 6% of cases; injuries of medium gravity – about 17%; easy injuries – 79% (among them, minor injuries with short-term health disorders make 55%, and 24% – without short-term health disorders). The group of severe injuries with injury of the head and limbs such as fractures includes 75% of cases. Internal and thorax injuries are defined most rarely. At that, a collision of high-speed trains results in 7% of fatal outcomes and in 57% of cases - in heavy bodily damages.

2. Analysis of latest achievements and publications

The most extensive researches in the field of the analysis of passenger safety in emergency are carried out in car industry. The majority of investigations are carried out abroad - in Europe and the USA.

There are two basic approaches to the assessment of levels in possible passenger injury in emergency cases – conducting experiments in natural conditions with the use of physical models of anthropometric dummies and a mathematical modeling of emergencies [1-5]. In domestic practice, the



investigations in this field are carried out only through the methods of mathematical modeling in the field of car industry, aircraft, cosmonautics, and providing safety of rides in amusement parks.

At present the simulation becomes widespread in different branches of science and engineering, which is substantiated by low costs for the preparation and fulfillment of researches and by the absence of destruction necessity of an expensive rolling-stock and also by a possibility of the analysis of many options in emergency development. All this became possible due to the development of software products realizing CAD/CAE-techniques.

The purpose of the investigation is the assessment of passenger safety at a longitudinal collision of a train with an obstacle using the methods of mathematical modeling in emergency with the use of current software products.

3. Simulation of human behavior in emergency

During the fulfillment of field studies, the authors used physical models of anthropometric dummies which allow reproducing human behavior in any situation including emergency with a high degree of accuracy. In the world practice, for the assessment of vehicle safety, anthropometric dummies of the family of Dummy Hybrid, SID, BioSID, BioRID, THOR are used. This totality includes dummies of men and women of different ages and dummies of children aged six, three and one.

A dummy is a very complex device having a form and mass distribution similar to a living person. It consists of separate elements jointed by means of joints able to reproduce human body behavior exactly under conditions of a collision and to measure forces, displacements and accelerations in different body parts.

When creating dummies, anthropometric characteristics of people of different sex, age, race are taken into account. Taking into account existing data for the definition of geometric and weight parameters of dummy elements, dependences of mass-inertial characteristics upon signs mentioned above are used.

The dummy application during simulation is based on the formation of a model describing a behavior of a real object with sufficient accuracy. In the investigation of passenger safety in emergency situations, an object is a human being. Thus, a passenger is substituted by a model of an anthropometric dummy whose characteristics correspond to the parameters of a physical dummy.

To assess human behavior in the emergency situation during formation of a computer model of an anthropometric dummy, the following assumptions and limitations were accepted:

- elements of a dummy model, modeling human body elements, are absolutely solid, that is, non-deformable under any circumstances;
- geometrical parameters and mass of elements of the model coincide with the corresponding parameters of human body elements;
- model elements are connected into kinematic pairs by spherical or cylindrical joints modeling human joints.

On the accepted assumptions concerning the basis of the model of the anthropometric dummy of Hybrid III 50th Percentile Male type, obtained from open sources in the environment of the “Universal mechanism” programming complex, a solid-state computer model of an anthropometric dummy is formed, the diagram of which is presented in Figure 1 [6]. A distinctive feature of the model developed is the existence of a joint, modeling a hip joint.

During modeling, a dummy was divided into elements: a head, a neck, an upper part of the body, a shoulder, a hip and so on, which were connected by means of joints into a single model. All elements of the dummy were modeled by perfectly solid bodies with real weight and geometric characteristics.

The simulation of swing joints imitating human joints was carried out with the use of rotating and generalized power swing joints with specified elastic-dissipative characteristics [7-11]. For the accurate description of the motion kinematics in human body parts in the dummy model, a limitation in a turn of its elements in accordance with real possibilities of human joints was introduced (Table 1) [12], and also a contact of elements was modeled within the model with the aid of a set of special contact elements of a sphere-sphere type allowing the limitation of the penetration of dummy parts into each other at their mutual

displacement. Swing joints allow orienting the elements of a dummy model in the room arbitrarily to obtain an essential passenger position during the assessment of safety.

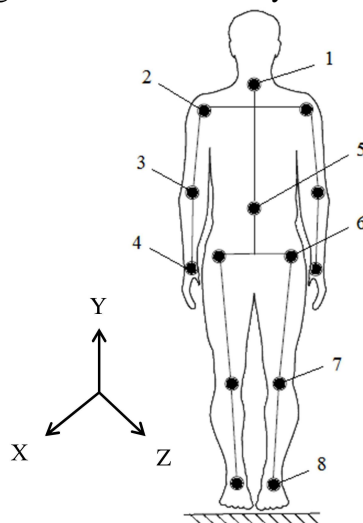


Figure 1. A structural diagram of the developed model of dummy Hybrid III 50th Percentile Male: 1 – joints modeling a cervical part of a vertebral (spine) column; 2 – joints modeling a humeroscapular joint; 3 – joints modeling an elbow joint; 4 – joints modeling a wrist connection; 5 – joint modeling a dorsolumbar spinal curvature; 6 – joints modeling a hip joint; 7 – joints modeling a knee joint; 8 – joints modeling an ankle joint.

For a more exact analysis of the degree of passenger possible injures during solid-state modeling, the account of mechanical characteristics of human biological tissue affected by impacts is necessary. This problem can be solved by means of the introduction of the compartment power contact elements between a dummy model and interior elements. Human muscles perceive impacts as a basic effect, when specifying contact rigidity parameters, the elastic-dissipative properties of dummy material are taken into account [13].

Table 1. The limitations of angular motions in joints

Joint	Rotation angles X, deg.	Rotation angles Y, deg.	Rotation angles Z, deg.
Cervical part of vertebral column	± 30	± 75	$+70 -60$
Humeroscapular joint	± 90	± 50	± 95
Elbow joint	–	–	$+145$
Wrist connection	–	± 60	± 85
Dorsolumbar spinal curvature	± 20	± 20	$+90 -20$
Hip joint	± 30	± 80	$+50 -120$
Knee joint	–	–	$+140$
Ankle joint	–	± 20	± 40

The anthropometric dummies applied in world practice are passive as they do not take into account a possibility of human active behavior and the reaction of muscular tissue to impacts. The accounting of these factors during modeling is a rather labour-intensive problem, which can result in the labour-output ratio increase during the model preparation, the fulfillment of numerical experiments in results processing. In this connection, the developed model of an anthropometric dummy is also passive. It allows carrying out the analysis of the character and levels of dynamic effects upon dummy elements: linear and angular motions, speeds and accelerations and also contact impact efforts. On the basis of

dynamic efforts obtained during modeling, affecting dummy elements, the assessment of levels of possible passenger injuries in emergency cases is carried out.

The procedure for the assessment of possible injury levels is based on the definition of universal criteria. In accordance with the normative documentation of the National Highway Traffic Safety Administration of the USA (NHTSA) [14], the following criteria of passenger injuries are emphasized: a craniocerebral injury criterion, a cervical injury criterion, a thorax injury criterion, a hip injury criterion.

The head (craniocerebral) injury criterion (HIC) is defined by the formula:

$$HIC = (t_2 - t_1) \left(\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a dt \right)^{2.5}, \quad (1)$$

where t_1 , t_2 – points of time expressed in seconds defining an interval between initial and end points of a head contact with an injuring thing, for which the HIC value is maximum; a – resulting acceleration expressed in gravity units, g .

When calculating a maximum HIC value, the authors do not take into account those values of it for which the time interval ($t_2 - t_1$) exceeds 36 ms.

The (NIC) neck injury criterion is defined through the formula:

$$NIC = \frac{F}{F_k} + \frac{M}{M_k}, \quad (2)$$

where F – axial compressive stretching force; F_k – axial force used for regulation; M – bending moment; M_k – bending moment used for regulation.

The (CTI) criterion of thorax injury is defined by the formula:

$$CTI = \frac{A_{\max}}{A_k} + \frac{D_{\max}}{D_k}, \quad (3)$$

where A_{\max} – maximum equation; A_k – acceleration used for regulation; D_{\max} – maximum thorax deformation; D_k – deformation used for regulation.

The (FFC) femoral injury criterion is defined on the basis of a compressive load expressed in kN, transferred along the axis to each hip of the dummy.

Besides, by a state standard of Russia, one more criterion of injury is defined – a (TCFC) talocrural injury criterion which is defined by the formulae [15]:

$$TCFC = \left| \frac{M_R}{(M_c)_R} \right| + \left| \frac{F_z}{(F_c)_z} \right|, \quad (4)$$

$$M_R = \sqrt{(M_x)^2 + (M_y)^2}, \quad (5)$$

where M_x – bending moment along axis X; M_y – bending moment along axis Y; $(M_c)_R$ – critical bending moment; F_z – axial compression force in the direction of axis Z; $(F_c)_z$ – critical compression force in the direction of axis Z.

When calculating criteria of injury, the authors take into account accelerations, stretching and compression axial forces, and also bending moments affecting dummy elements. At that, for each criterion on the basis of the analysis of emergency consequences, normalized values are defined.

4. Assessment of passenger safety in emergency situation

With the use of the developed computer model of an anthropometric dummy, a number of investigations is carried out on the assessment of passenger safety at an emergency collision of a train with an obstacle on a railway track.

For that, a computer model of the collision of a passenger train is developed, consisting of a locomotive and four single-type passenger cars with an obstacle as a lorry at a railway crossing. This scenario reflects the most likely emergency situation in railway transport connected with a longitudinal collision of a train with an obstacle. As a tool of the investigation, the “Universal

mechanism” software complex was accepted.

For the assessment of injuries got by a passenger during a collision of a train with a lorry in the computer model of the passenger car, the first one in the motion direction, a solid-state model of the compartment with a thorough description interior is included. The interaction of passengers with interior elements in the compartment was carried out by means of special contact elements of the software complex.

When modeling, the most likely unpleasant situation – a passenger sitting with his face in the direction of the movement near the window in the first compartment – is considered.

According to the results of modeling, values of dynamic forces affecting the elements of the anthropometric dummy are obtained, on the basis of which injury criteria are calculated. Figures 2-4 show diagrams of changes in the accelerations of a dummy head, forces acting on the neck and the hip of the dummy starting from the collision moment.

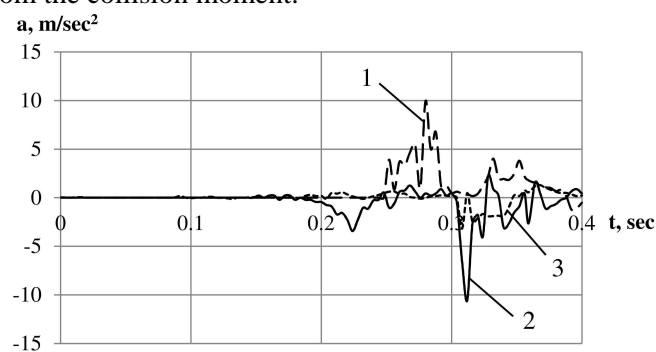


Figure 2. A diagram of changes in the accelerations of the dummy head in time: 1 – vertical accelerations; 2 – longitudinal accelerations; 3 – lateral accelerations.

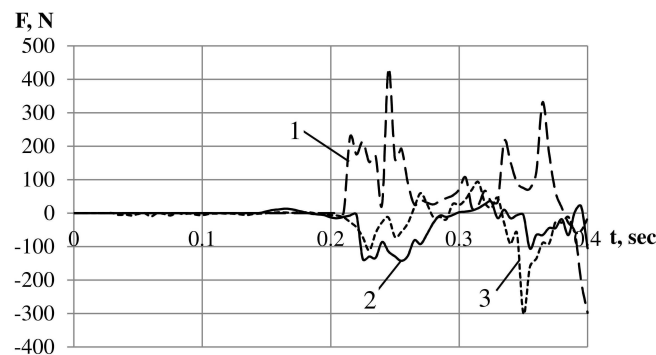


Figure 3. Diagrams of changes in forces acting on the neck of the dummy, in time: 1 – vertical forces; 2 – longitudinal forces; 3 – transverse forces.

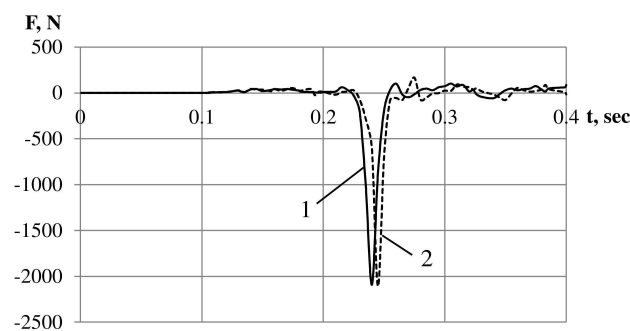


Figure 4. A diagram of changes in compressive forces acting on a dummy hip, in time: 1 – left leg; 2 – right leg.

The analysis of modeling results and computations has shown that under conditions of the scenario calculated during the collision, the passenger sitting near the window in the direction of the train

movement does not get injuries threatening life and health. The computed values of all criteria under consideration do not exceed the specified values (Table 2), which indicates an acceptable level of passenger safety. In similar emergencies, easy injuries are the most likely.

Table 2. Criteria of passenger injuries during the collision

Injury criterion	Specified value	Calculated value
Craniocerebral injury criterion (HIC)	1000 units	41.3 units
Neck injury criterion (Nij)	1.4 units	0.137 units
Hip injury criterion (FFC)	10 kN	2.1 kN

5. Conclusion

The further increase in the assessment accuracy of possible levels of passenger injuries is possible on the basis of multichoice computations, taking into account a train composition, different speeds of collision, passenger positions in a car, as well as on the basis of computer models of different anthropometric dummies.

On the basis of the refined data on people injuries in accidents, it is possible to develop recommendations for the updating of the domestic passenger rolling stock with the purpose of the increase of its passive safety.

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