Pedestrian collision with heavy vehicle

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The proceeding deals with the passive safety of commercial vehicles with the respect to a pedestrian collision. The experimental and mathematical methods are used. Based on the executed experiment, there are created some mathematical models in commercial software packages. The computer simulations run on the software packages SIMPACK and MADYMO. There was performed a sensitivity analysis and biomechanical criteria of injuries were evaluated. The optimisation process is focused on the shape of the front part of the vehicle. A biomechanical assessment is included. An evaluation of technical conditions of trucks on roads is an integral part of the study.

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Introduction

The statistics of traffic accidents shows that problems of collisions of pedestrians with trucks are very serious. The statistic data can be processed in many ways to try to find the reasons, which cause the most serious consequences. Nevertheless, also a relatively simple view to the statistics shows that the number of deaths as a consequence of a collision with a pedestrian is 1.5-3 times higher in case of collisions with trucks than with cars. It is certainly influenced by a higher level of incompatibility of trucks, nevertheless, a lower level or absence of technical measures to reduce the consequences of collisions of trucks with pedestrians plays certainly an important role.

A creation of a mathematical model of a collision of a pedestrian with a truck and its use for an analysis of the course of the collision is the goal of this paper. Generally, mathematical models can be used quite well within a certain data field, which is verified by a validation experiment. The execution of an experiment imitating a collision of a pedestrian with a truck is very demanding, therefore we have used a vehicle of a category N1 with a vertical front wall and used this experiment for simulations using a computing system SIMPACK. The first part has therefore been executed by a PC simulation of a collision of a pedestrian with a truck, corresponding to an experimentally performed collision of a dummy with a truck and compare the results. The following theoretical analysis includes a sensitivity analysis of input parameters in the course of the collision. The monitored parameters include the shape of the front part and the size category of the pedestrian. A system MADYMO was the simulation tool in this case. In addition, the results verify a good compliance of simulations on different systems.

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Description of the experiment

A collision of a dummy MANIKIN (producer: ÚSMD/DEKRA under a licence TNO – a dummy for testing of safety belts of cars) with a truck N1 at 25km/h. The dummy is in the position with its face towards the colliding truck. The dummy includes two accelerometers, one in the cavity of the head and the other inside the chest, both are connected to an electronic recording equipment. The course of the collision is shown on the pictures of the *Fig. 1*.

Fig. 1– Experiment using a vehicle category N1.

Description of the mathematical model

1) The dummy
    - The parameters, specifying its properties (weight, dimensions, joints, etc.), show that it is a dummy Hybrid III – 50 %.
    - The contacts of the dummy parts with the vehicle surface are made using movable Move markers for creation of contacts of 3D surfaces The realisation of the power contacts themselves is executed using an insertion of a non-linear power element with a hysteresis between two corresponding move markers.
    - The specific deformation characteristics of the contact dummy – truck surface, were used in the simulation.
2) Impactor
    - The dimensions of the critical parts comply with the chosen truck.
    - Due to a complicated creation of surfaces the radii of curvatures of the bonnet and the window are made with greater tolerances

Description of the performed simulation

There was performed a simulation of a collision of a dummy (Hybrid III) from the left side, with basic position, at a speed of collision 25km/h, with an impactor corresponding to the truck N1 front part, see *Fig. 2*.

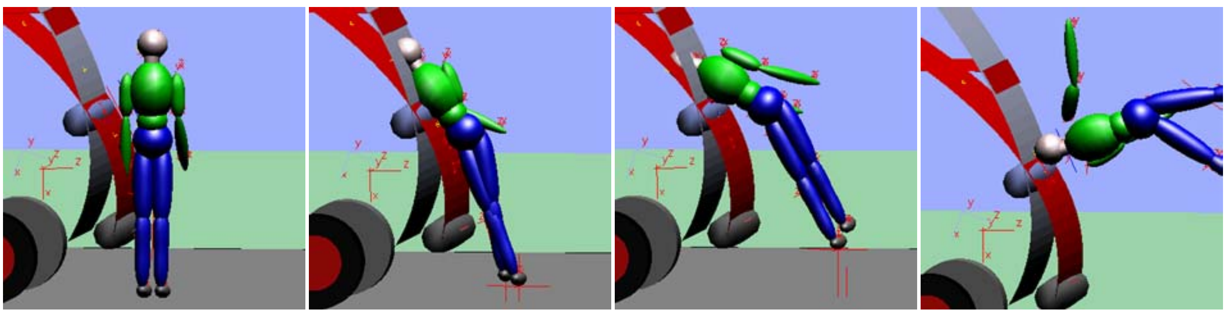
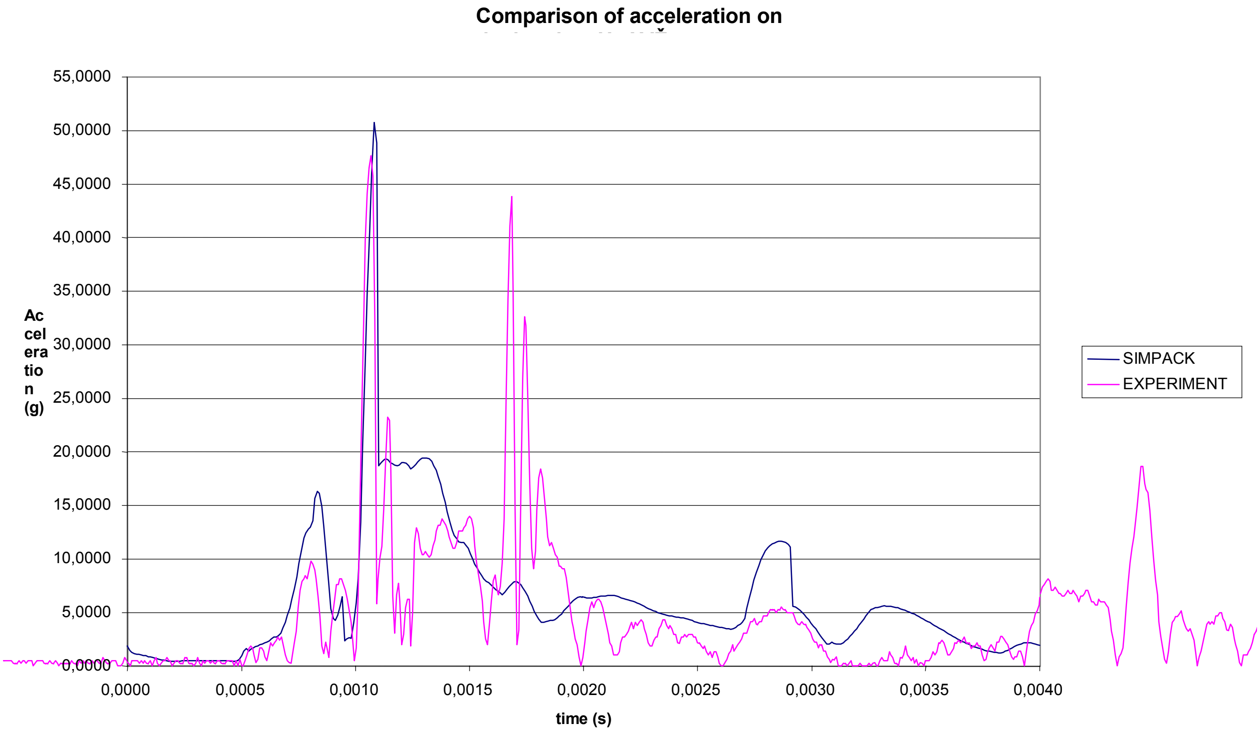


Fig. 2 – Simulated course of the action

Comparison of results of the simulation with the experiment

The results of the simulation and experiment are presented in time records of values of the absolute acceleration of the pedestrian's head and chest. These data are illustrated in graphs and compared. See for example *Graph 4*.



Graph 4 – Time record of absolute acceleration of head

Identification of the origin of acceleration of the head in time t in the collision in *Graph 4:*

- $t \in (0{,}05;0{,}1)$ a reaction of the head on the impact of the bumper to the legs
- $t \in (0{,}1;0{,}15)$ breaking of the front glass by head (the main peak of the acceleration is followed by a short platform of acceleration approx. 20g, which will probably be caused by the reaction of the head on another movement of the dummy body)
- $t \in (0{,}15;0{,}2)$ impact of the head on the instrument panel (note: the instrument panel is missing in the mathematical model of the impactor)
- $t \in (0{,}25;0.3)$ a slight bump of the head on the front part of the truck when falling down

The comparable identification was made on the record of the chess acceleration for better validation of the model.

The task of this work included a simulation of a man with a truck and a comparison of the results with the results of the experiment. Despite the fact that I have used another dummy model for the PC simulation (Hybrid III) than as used with the experiment (MANIKIN), it is obvious that the results are very similar each other.
The similarity of the results of the PC simulation and the experiment prove the correctness of the use of the dummy for the PC simulation mathematical model compared with the one used for the experiment. Various dummies of some producers have to be able to provide the same data, or in another words, they have to simulate behaviour of a human body, i.e. to meet a

requirement of a bio-fidelity. In case of the dummies of various structures, which were used in various tests, there must be met requirements of a proper use.

Simulation of a collision of a pedestrian with a truck

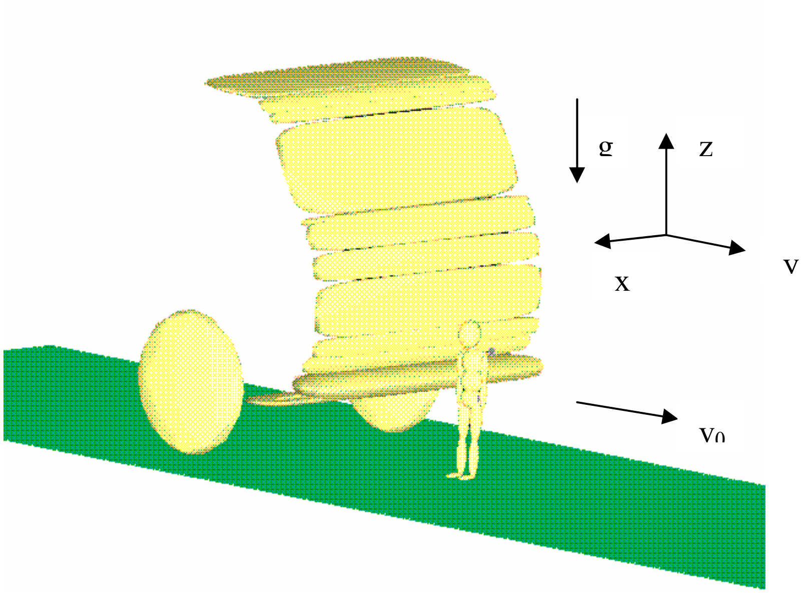


Fig. 3 – Simulation of a collision of a pedestrian with a truck

The other part simulates a collision of a truck with child and adult dummies – *Fig 3*. There are also mentioned values of biomechanical injuries. The alternatives (see the attachments) are given by various shape designs of the front part of the truck. In case of the child dummy, if seen from the side, as the first there comes a contact of the bumper with the right arm, further the bumper bumps to the pedestrian's body in the area of his belly. The bump lifts slightly the pedestrian and this causes a contact of the dummy head with the cooler of the truck. Then the pedestrian starts to fly and the head has the first contact with the roadway after the landing. This is very disadvantageous, particularly due to increase of the power and acceleration. After the impact of the head the body falls on the roadway and the pelvis and knee joints transfer the biggest bump in this phase. The whole body of the pedestrian is then dragged for quite a long period on the roadway. If seen from the front side, it is obvious that the whole body turns to the right after the contact of the head with the roadway and the pedestrian remains lying in a position parallel with the front part of the truck. It is also evident that any part of the body cannot come into contact with wheels of the truck.

Alternative	v1, child, v=25	v2, child, v=25	v3, child, v=25
Max. acceleration in the head	256g	111g	225g
Max. deformation of the skull	25.8mm	11.6mm	12.7mm
HIC (15 ms)	2318.2	507.3	1010.7
3MS chest	105.5g	156.4g	63.1g
TTI	99.9	245.4	125.2
Max. acceleration in the pelvis	155g	86.3g	354.9g
Max. power to the pelvis	4386N	3241N	7248N
Max. power on the right thigh	2533N	6698N	3356N

Tab. 1 – Biomechanical criteria of injuries at the speed 25km/h

In the case of the alternative with an adult dummy there is apparent a contact of the right leg (the thigh area) with the bumper. After throwing of the body from the truck bonnet there can be seen a contact of the left leg with the bump in the area of the knee joint. The dummy falls during interrupted dragging of its soles on the roadway. The dummy falls on its back side, the first with its pelvis area onto the roadway. This causes its immediate rebounding, then the pedestrian falls on his back part. The contact of the head with the roadway comes at the moment when the whole body is above the roadway due to the rebound of the pelvis. The body turns partly during the flight, therefore the pedestrian falls on his right side. The pedestrian completes the simulation lying on the back. If seen from the front it is obvious that the pedestrian remains approximately along the vehicle axis. After the bump there can be seen a considerable orientation of the head in a contact with the right shoulder.

Alternative	v1, adult v=25	v2, adult, v=25	v3, adult, v=25
Max. acceleration in the head	131.7 g	117.3g	150g
Max. deformation of the skull	27.7 mm	17.8mm	19.8mm
HIC (15 ms)	1149.1	470.1	880.4
3MS chest	81g	72.8g	72.3g
TTI	83.8	60.4	73.8
Max. acceleration in the pelvis	91.5g	39.5g	65.7g
Max. power to the pelvis	8556N	8902N	10848N
Max. power on the right thigh	11104N	26460N	12367N

Tab. 2 – Biomechanical criteria of injuries at the speed 25km/h

The course of the collision is influenced by many parameters. The shape of the truck front part affects considerably the acceleration and trajectory of movements of particular parts of the body. The shape can also reduce the chance that the vehicle could run over the pedestrian. The principal solution therefore means such design of the shape of the cabin, which could change the momentum at the moment of a collision in the area. This could be relatively advantageous for the pedestrian. In addition, it is always necessary to come out from the individual dispersion of dimensions, properties of tissues and bones, joints, muscles, etc. An improvement in the critical area, e.g. of the head, is also usually compensated by a higher loading of other parts of the body, e.g. knee joints, etc. (a principle of a "sacrifice of less important organs at the cost of a survival of the pedestrian"). A wedge-shaped front part of the truck has positive effects to the consequences of the collision, however, the course and mechanism of the bump is very different from a collision with a car.

The rigidity of the contact surface is the principal material property, which affects the course and also consequences of a collision of a pedestrian with a vehicle. Just the possibility of a deformation has a great importance on the values of the maximum acceleration and stress. In the view of the pedestrian's safety a flexible surface (e.g. a bonnet of a car) is very suitable.

The simulations verified that smoothness of the surface and smoothness of transitions between parts of the structure plays a very important role in designs of safe vehicles. It is clear that as smoother and unbroken vehicle surface, as lower consequences of a bump to the pedestrian, e.g. using of so-called „bullbars“ (covers of front lights). Sizes and properties of the contact surface and thus the course and consequences of a bump affect details of the vehicle body, such as covers of front lights, axes of wipers, rails, frames and also producer's emblems. These have smaller contact surfaces and higher rigidity than the other parts of the vehicle and there is also a chance that such emblem could catch the pedestrian.

A majority of the operated vehicles has unfavourable properties in case of a collision with pedestrians. The shapes, used materials and current requirements for vehicles cause this in general. Their structure, particularly the structure of the front part, is very rigid. The reason can be found in requirements for a passive safety of the passengers and conditions of so-called insurance collisions. Contacts of heads of pedestrians with vehicles (primary bumps) or with roadways (secondary bumps) are the dominating causes of serious injuries, often with a consequence of death. The seriousness of injuries of various parts of the body can be derived from values of powers and accelerations in the performed simulations.

The technical measures on vehicles in the view of shaping and rigidness of the front part are very complex, nevertheless, a certain development can be expected in near future. However, its real effectiveness is rather unclear. This can also be found in the given tables, where the individual alternatives 1 to 3 with increasing inclination of the front wall do not prove any unambiguously positive development in biomechanical criteria of injuries.

It is very difficult to develop suitable safety measures in this field. An absolute separation of pedestrians from the road traffic (overpasses, underpasses, raised paths for pedestrians, etc.) could be considered as the ideal solution. However, this is very demanding solution due to financial and spatial reasons.

Evaluation and conclusion

The paper includes mathematical and experimental approaches to the solution of problems concerning to collisions of pedestrians with vehicles. It is clear that a validated mathematical model can be a good tool for a sensitivity analysis of the problem and its optimising. The technical solution how to reduce the consequences of collisions of pedestrians with trucks is, however, very complicated, particularly due to great incompatibility of the bumps. However, the statistics shows that the problems of collisions of pedestrians with trucks are so serious that it would be good to encourage some activities in this field, see the measures of vehicles in the category M1. Particularly in the category N and M2, M3 there may be anticipated that an introduction of intelligent and adaptive retaining systems may bring improvements in the field of traffic safety.

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