Case Study Regarding the Motor Vehicle – Pedestrian Collision

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Abstract: Statistics show that at the world level more people die in road traffic accidents than in armed conflicts. The researches carried out in view of reducing the number of victims as well as in view of diminishing the degree of injuries in pedestrians have been numerous in the last decade. EURONCAP association has proposed the car manufacturers, through the EEVCWG17 directive, a partial solution with regard to the changes that must be brought to the front end of the vehicle. Through the present paper the authors have analyzed some theoretical and experimental aspects regarding the frontal collision between motor vehicles and pedestrians, looking at the kinematics and dynamics of impact occurrence for a better understanding of the phenomenon. Likewise, theoretical results were compared with the experimental ones in view of further improving programs and calculation models.

Key-Words: - Automotive, Pedestrian, Accident Simulation, Accident Reconstruction

1 Introduction

The study of injuries suffered by persons involved in road traffic accidents represent, for motor vehicles designers, a good method to obtain data that contribute to improving road safety, particularly passive safety. This process develops directly (the results of mixed analyses – medical and engineering-oriented – of the frequency of body injuries as well as of their causes are transposed in adequate designing solutions for different parts of the motor vehicle) or indirectly (when these analyses are used to simulate real accidents in laboratory).

During collisions, the human body is subjected to extreme loads that are mainly due to high accelerations and decelerations (at severe collisions they reach values of more than 30 g) which generate great forces of inertia. Another factor that determines injuries of the human body are the deforming elements of the motor vehicle's body. During collision, these elements act upon the various anatomical parts, causing serious injuries.

In Romania, road traffic accidents cause more than 2800 deaths and more than 7700 serious injuries every year; these figures, considering the dimensions of the country, are high. The mean value between traffic values and number of accidents is six times higher in Romania than that recorded in the European Community. Bone and internal organ injuries require large funds from the budgets of each country.

In this paper, the authors compared the values related to the kinematics of body segments experimentally obtained and the values related to the multimass mathematical model of the pedestrian.

The criteria used in order to estimate the traumas of the human body are head and thorax decelerations as well as impact speeds of these human body segments with motor vehicle's parts.

2 Testing scenarios and mathematical model

The basic principle when it comes to protect life of both pedestrians and motor vehicle occupants is to reduce the potentially injurious forces by absorbing a part of the motor vehicle's kinetic energy. This may be achieved by deforming or by destroying certain parts of the motor vehicle the pedestrian comes into contact with.

Provided that, while in motion, the pedestrian's body hits certain objects, these objects absorb part of the kinetic energy and the impact forces decrease. The issues to be raised make reference to the energy a deforming body can absorb and the force needed for the deformation to be produced.

A simplified relation of the connection between the kinetic energy of the body and the space needed for energy absorption is:

$$F \cdot d = \frac{m \cdot v^2}{2} \qquad (1)$$

where ***d*** stands for the distance required to stop the body, ***F*** stands for the average force occurring during the impact, ***v*** stands for the body's speed before the impact. It is easy to understand that head protection calls for lowest possible values of ***F*** and greatest possible deformations of the motor vehicle's parts.

The study of phenomena occurring during the motor vehicle-human being interaction entailed the use of various computer-based mathematical models, based on the dynamics of rigid bodies, in order to simulate the motor vehicle-pedestrian impact. Therefore, the specialist literature provides analyses that used commercial software as well as specific models. Other researchers investigated the efficacy of bi-dimensional models with different complexity degrees. The commercial program MADYMO was used to create bi-dimensional models of the pedestrian with two, five and seven rigid body segments as well as a tri-dimensional model whose body is made up of fifteen segments, figure 1. [4]

Tests results were compared with those obtained following the experiments with dummies.

In order to define the tests the following two situations were considered representative for the motor vehicle-pedestrian accidents.

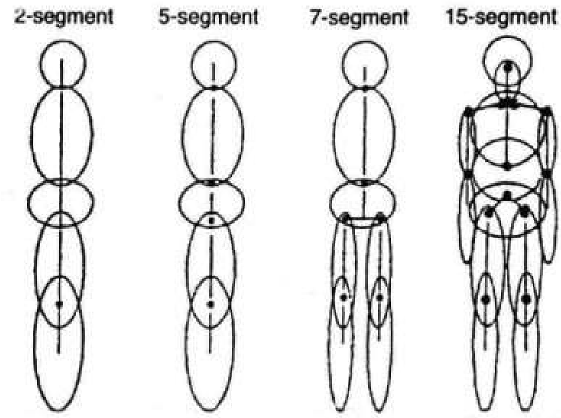

Fig 1. Dummies with different complexity degrees

- Pedestrian in lateral position (crossing the street) hit with the front end area of the braking vehicle - scenario (a);
- Pedestrian in frontal position, coming into a frontal collision with the vehicle traveling at constant speed – scenario (b);

Fig 2. The pedestrian dummy crossing the street

The geometry of the vehicle can have a large effect on the pedestrian dynamics, so the used model allows the use of different vehicles shapes.

The motor vehicle used for tests was towed on the test road and accelerated to a speed of 30 km/h. Just before the moment of impact the motor vehicle was braked. In order to find out the average deceleration of the motor vehicle, the braking marks were measured. Statistical data showed that most of the road traffic accidents involving pedestrians occur at speed of up to 30 km/h, in most cases the motor vehicles being in braking operation.

2.1 Multimass mathematical model of the pedestrian

A multibody is a system of rigid bodies interconnected by joints. With this model, vehicle - pedestrian impacts with other types of multibodies can be modeled almost as easily as vehicle - vehicle impacts are. With the use of multibody systems it is also possible to correlate pedestrian and occupant injuries to vehicle damage areas. The model has the capability of dealing with different pedestrian statures (size and mass) under different initial conditions (standing, walking, running).

The multibody pedestrian body elements (head, torso, pelvis, etc.) are interconnected with pivoting joints. For each body there are different properties such as geometry, mass, contact stiffness and coefficients of friction. A general ellipsoid of degree n specifies the geometry for each body.

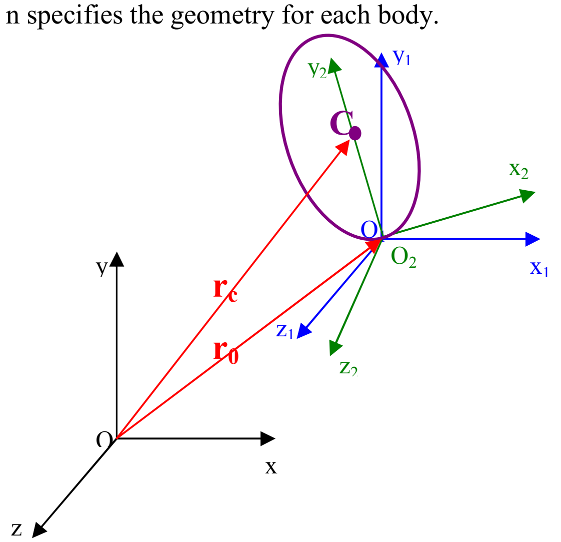

Fig. 3 Schema de mişcare a unui corp solid

Figure 3 shows the process through which a solid body is hit at a point O1 = O2, eccentrically situated with respect to the O2y2 axis. The xOyz axis system is fixed, connected to soil, the x1O1y1z1 system is mobile, in translation motion with respect to the fixed system, and the x2O2y2z2 system is connected to the body, whose center of gravity is at Cg point. Thus, the point O1 = O2 is instantaneous center of rotation and the body rotates around it with ψ, θ and φ angles. The xOyz system is connected to the x1O1y1z1mobile system through the position vector r0 and to the x2O2y2z2 system through the position vector of the center of gravity rc. O1 is the pedestrian's instantaneous center of rotation during the impact with the vehicle. The rotation with the three angles previously mentioned generates, around the systems' axes, the versors of the new positions of the x2O2y2z2 mobile system connected to the body.

The body rotation is due to occur throughout three stages, as follows:

a) Rotation with ψ angle around the y axis (y1 = y1')

$$\begin{cases} \vec{k'} = \vec{k}\cdot\cos\Psi + \vec{i}\cdot\sin\Psi \\ \vec{i'} = -\vec{k}\cdot\sin\Psi + \vec{i}\cdot\cos\Psi \\ \vec{j'} = \vec{j} \end{cases} \tag{2}$$

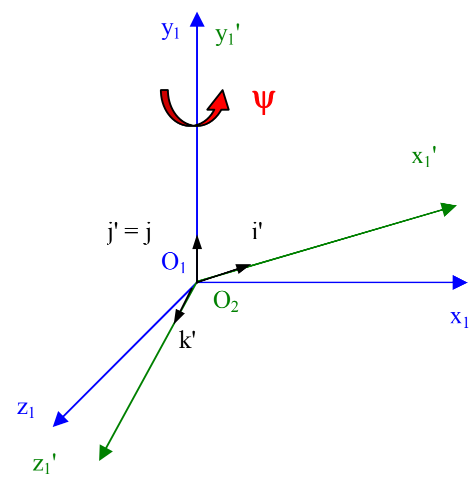

Fig. 4 Rotation with ψ angle

b) Rotation with θ angle around the z axis (z1' = z1")

$$\begin{cases} \vec{k''} = \vec{k'} \\ \vec{i''} = \vec{i'}\cdot\cos\theta + \vec{j'}\cdot\sin\theta \\ \vec{j''} = -\vec{i'}\cdot\sin\theta + \vec{j'}\cdot\cos\theta \end{cases} \tag{3}$$

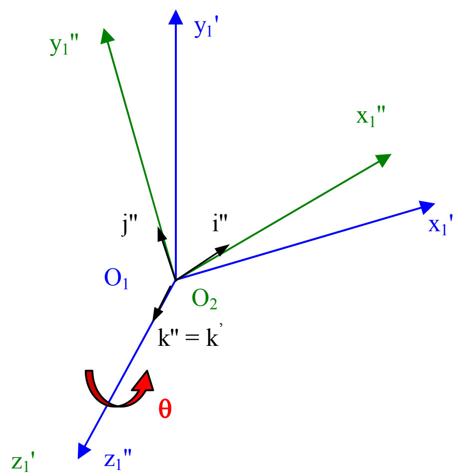

Fig. 5 Rotation with θ angle

c) Rotation with φ angle around the x axis (x1" = x2)

$$\begin{cases} \vec{k_2} = \vec{k''} \cdot \cos\varphi - \vec{j''} \cdot \sin\varphi \\ \vec{i_2} = \vec{i''} \\ \vec{j_2} = \vec{k''} \cdot \sin\varphi + \vec{j''} \cdot \cos\varphi \end{cases} \quad (4)$$

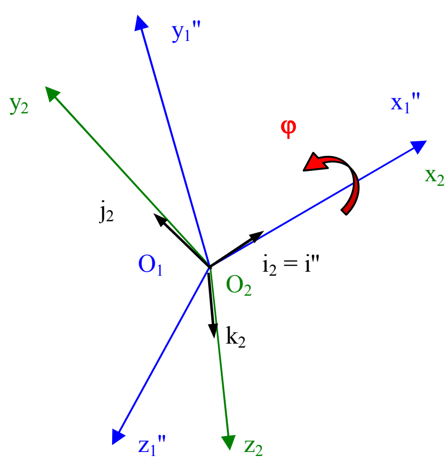

Fig. 6 Rotation with φ angle

Once the calculations are done, the relations for the versors of the coordinates system x2O2y2z2 are to be obtained.
It is noticed that the y2 - axis versor is j2 and it has the following position as compared to xOyz system:

$$\overrightarrow{j_2} = \overrightarrow{u_{cg}} = \begin{Bmatrix} u_x \\ u_y \\ u_z \end{Bmatrix} = \quad (5)$$

$$= \begin{Bmatrix} \sin(\Psi)\cdot\sin(\varphi) - \cos(\Psi)\cdot\sin(\theta)\cdot\cos(\varphi) \\ \cos(\theta)\cdot\cos(\varphi) \\ \cos(\Psi)\cdot\sin(\varphi) + \sin(\Psi)\cdot\sin(\theta)\cdot\cos(\varphi) \end{Bmatrix}$$

For the simulation of the multibody system, the external forces (gravity, contact forces, frictional forces and joint forces) on each body are calculated during each time step. Once the external forces are determined, the movement of each body is calculated independently by solving the equations of motion numerically. The equations of motion use the balance of forces and conservation of angular momentum to describe the movement of each body i from the influence of external forces and moments [3].

Typically a symmetric mass tensor is used for each body to represent an ellipsoid. However, ellipsoid are only used to specify the body shape for the calculation of contacts and therefore any mass tensor can be specified.
For the integration of these equations an explicit Euler method is used. Typically the time step needed varies from 0.1ms to 1ms.

In order to simplify the relations, there is described the motion of a pedestrian, made up of two masses, with degrees of freedom in 2D, this model being easily modified by adding additional masses.

At time $t \neq t_0 = 0$, after the motor vehicle has acted upon the pedestrian's knee, the contact point being A, in the impact configuration of the pedestrian in lateral position with the front end of the vehicle, the pedestrian is found in the position presented in figure 2. In this first stage of the impact it is considered that the instantaneous center of rotation of mass one of the pedestrian is at the contact point with the vehicle's bumper, mass two rotating around the hip joint. The hip joint is considered a cylindrical joint, when solving the plane problem, having a rigidity coefficient k_{21}, which stimulates the muscular tonus.
The coordinates of the centers of mass, on X and Y axes, of the two body segments are displayed according to the diagram in figure 7.

Through derivation, there are to be obtained the speeds on the two axes of the XOY system, corresponding to the centers of mass of the two segments of the pedestrian's body

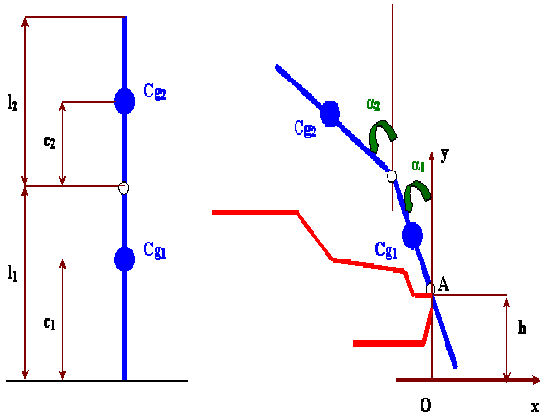

Fig 7. Mathematical model – general diagram

$$\begin{cases} x_{cg1} = -(c1-h)\cdot\sin(\alpha_1) \\ y_{cg1} = h+(c1-h)\cdot\cos(\alpha_1) \end{cases} \tag{6}$$
$$\begin{cases} x_{cg2} = -(l1-h)\cdot\sin(\alpha_1) - c2\cdot\sin(\alpha_2) \\ y_{cg2} = h+(l1-h)\cdot\cos(\alpha_1) + c2\cdot\cos(\alpha_2) \end{cases}$$

$$\begin{cases} \dot{x}_{cg1} = -\dot{\alpha}_1\cdot(c1-h)\cdot\cos(\alpha_1) \\ \dot{y}_{cg1} = -\dot{\alpha}_1\cdot(c1-h)\cdot\sin(\alpha_1) \end{cases} \tag{7}$$
$$\begin{cases} \dot{x}_{cg2} = -\dot{\alpha}_1\cdot(l1-h)\cdot\cos(\alpha_1) - \dot{\alpha}_2\cdot c2\cdot\cos(\alpha_2) \\ \dot{y}_{cg2} = -\dot{\alpha}_1\cdot(l1-h)\cdot\sin(\alpha) - \dot{\alpha}_2\cdot c2\cdot\sin(\alpha_2) \end{cases}$$

Lagrage method is to be approached in order to find out the unknown

$$\frac{\partial}{dt}\left(\frac{\partial Ec}{\partial \dot{q}_i}\right) - \frac{\partial Ec}{\partial q_i} + \frac{\partial V}{\partial q_i} = 0\,, \tag{8}$$

where for our case i=1,n, and q_i are angles α_1 and α_2 for the case presented

$$Ec = \sum_i Ec_i \tag{9}$$

$$Ec_i = \frac{m_i\cdot vcg_i^{\,2}}{2} + \frac{J_i\cdot\dot{\alpha}_i}{2} \tag{10}$$

$$vcg_i^{\,2} = \dot{x}_{cgi}^{\,2} + \dot{y}_{cgi}^{\,2} \tag{11}$$

$$V = \sum_i\left(m_i\cdot g\cdot y_{cgi}\right) + \sum_i \frac{k_{i,i-1}\cdot(\alpha_i-\alpha_{i-1})^2}{2} \tag{12}$$

Where:

Ec – kinetic energy;
V – potential energy
m_i – masses of the body segments making up the pedestrian;
J_i – moments of inertia of the pedestrian masses;
Vcg_i – speeds of center of masses of pedestrian masses;
k_i – rigidity coefficients in the joints of the pedestrian body;

Through replacement process in relation (8) and through its differentiation, a system of differential equations is to be obtained in unknown α_1 and α_2.

3 Theoretical results

Statistics drawn up in hospitals show that the probabilities for the anatomical parts to suffer injuries during an accident are different. The head is the anatomical part which is most likely to be injured. This may be explained through the multitude of factors acting upon the head during collision. The most dangerous situations (head injury) are the frontal impact (the head is submitted to a secondary impact, hitting the windshield, the hood or the wheel, depending on the position of either pedestrian or vehicle occupant) and those involving front-end and rear-end collisions (when loads are mainly due to the relative motion between the head and the body).

On the basis of the mathematical model presented in the previous section, simulations were carried out with regard to the collision presented in scenario (a) motor-vehicle – pedestrian crossing the street. The simulations were made with the PC Crash 8.0 program, choosing a dummy with a height of 1,83 m and a weight of 73 kg. In head-neck and hip-thorax joints there were introduced moments of resistance variable in time, according to the relative angle between the body segments mentioned.

The software allows us to visualize the graphs for accelerations, speeds and contact forces for all body segments that make up the human body.

The pedestrian model used in this simulation is made up of 16 rigid bodies, each body simulating a certain anatomical region of the body. The software made it possible to simulate the pedestrian's position, i.e. walking position. The friction coefficients between the pedestrian and the vehicle as well as the friction coefficients between the pedestrian and the ground were established after the pedestrian fell off the vehicle. Likewise, the pedestrian may be given a certain walking speed.

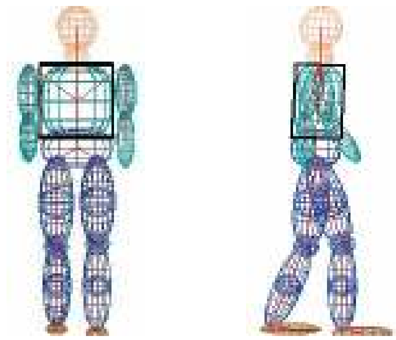

Fig. 8. PC-Crash Dummy model

The initial speed of the motor vehicle was of 30 km/h, just like in real situation; at the moment of impact a braking deceleration of 3,5 m/s^2 was applied upon the rear axle wheels.

The impact simulation is presented in figure 9. It is noticed that for the first contact – bumper-pedestrian’s leg contact – the impact occurred at knee level. The leg then is dragged under the vehicle from below the knee and the upper leg is hit for the second time by the front edge of the hood at hip level. The film shows that the pedestrian slides down the hood. After the first impact the pedestrian was imprinted a body rotation around the sagital axis and around 200 ms from the first contact with the vehicle the pedestrian hits the hood with the head.

Fig. 9. Impact simulation at 0, 50, 100, 150 and 200 ms

The head and thorax accelerations were recorded and are subsequently presented in figure 6. Just like in the case of experimental researches, the impact covered two main stages. The first stage approached in the present paper, starts at the moment of the first contact between the bumper and the pedestrian’s leg and ends at the moment the pedestrian hits the motor vehicle’s windshield or hood with the head. In theoretical simulations this interval lasts for about 0,225 seconds, slightly more increased than in experimental researches. The maximum value of pedestrian’s head deceleration is of 70 g. The maximum level of the deceleration obtained is not as important as the period covered by the maximum level admitted, this being in fact a criterion to establish the head traumas, the HIC criterion.

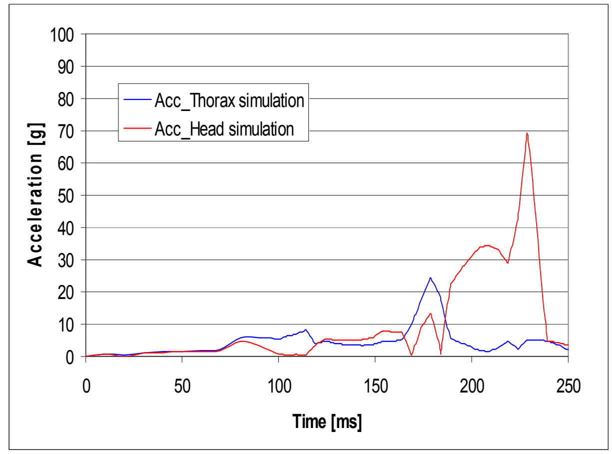

Fig 10. Theoretical results obtained.

4 Experimental tests

The experimental tests used a dummy built by the authors, figure 11. The weight of the dummy skeleton is 10 kg distributed as follows: 4,9 kg - the body together with the head, without hip joint, and 5,1 kg - lower limbs together with hip joint. The total weight of the dummy is 73 kg, the dummy being linked with elastic elements made of rubber as muscles. The dimensions of the dummy and the masses of the main regions of the body are given in tables 1 and 2.

Table 1

Dimension of the body segment	**[cm]**
Head circumference	59
Chest circumference (dressed)	108
Hip circumference (dressed)	89
Height of the head + neck	29
Distance from shoulder to elbow	28
Distance from elbow to arm wrist	25
Height to which the knee is placed, from the soil	47
Distance from hip to knee	49
Height of the body	58

Table 2

Body segment	**Mass [kg]**
Head + Neck	5
Body + arms	40
Legs + hip	28
Total body	**73**

Dummy instrumentation includes two triaxial accelerometers set in the head and in the thorax. Optionally, displacement transducers may be assembled to measure the deflection of the ribcage and strain gauges may be set on bones to measure the forces occurring during the impact.

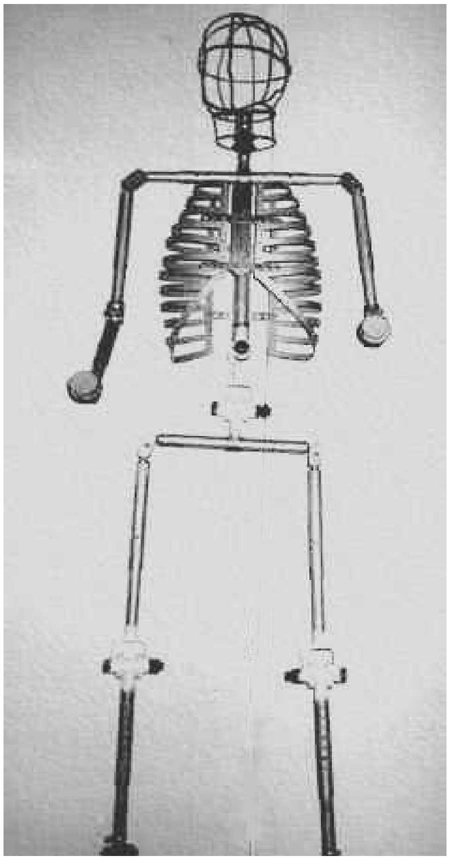

Fig 11. Bone structure of the dummy

A moment of resistance in joints is achieved by diminishing the clamping force in the respective joint and by assembling elastic rubber elements between the body segments linked through that joint.

By clamping or by loosening the joints a mono-mass or multi-mass dummy may be obtained. The maximum number of the masses of the model built is 11, see figure 11.

The dummy was instrumented with two Bell & Howell accelerometers of type 4-204-0001, assembled in the center of gravity of both head and thorax. In view of a better adjustment of the dummy's head, changes were made in order to fix it in three points placed on shoulders and on the vertebral column. In order to measure the thorax accelerations, a second accelerometer of the same type was assembled on the vertebral column. The accelerometers were assembled with axles parallel to the three anatomic planes of the body (coronal, sagittal, transversal). X and Y axes, on which the accelerations were recorded, are contained in the sagittal and coronal plane, and Z axes are parallel to the transversal plane, see figure 12.

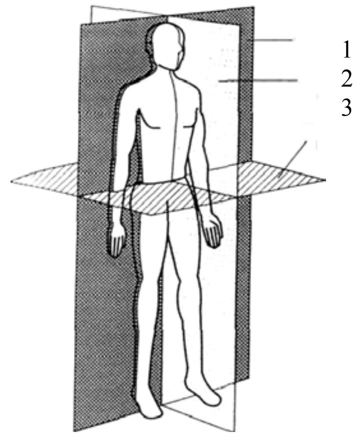

Fig 12. 1 – coronal plan, 2 – sagittal plan, 3 –transversal plan

The values obtained following the tests are presented in figure 13.

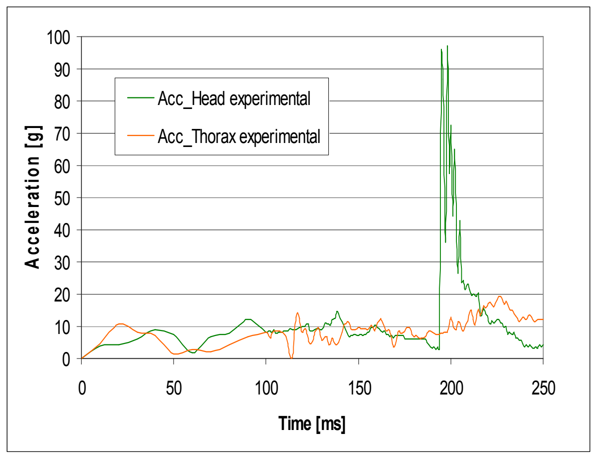

Fig. 13. Experimental results

4.1 Preparing the motor vehicle

The motor vehicle used was Dacia Nova. The vehicle was tested at a weight of 1024 kg, and empty fuel tank. The front end and the hood were dyed in order to trace the areas with different potential for injury of the pedestrian and to facilitate the image analyses with the FALCON Germany soft. Two dummies Hybrid II Fyrst Technology USA were set inside the vehicle as testing elements.

A special braking system with electrical triggering through cable, figure 14, was assembled in the motor vehicle's boot. The aim was to trigger the braking system at the moment of impact with a pedestrian dummy and to avoid its destruction during the impact with a fixed collision barrier (170 tonnes + metallic barrier for collision) placed at about 15 meters from the impact area. The vehicle was towed on the test road with a special installation, whose parameters may be modified with regard to the speed of tests development.

The speed at which the vehicle was towed on the collision-designated test road was 30 km/h; the vehicle was completely uncoupled from the pulling installation shortly before the impact, it rolled freely for a certain time and then it was braked on the rear axle with an average deceleration of 3,5 m/s^2 just before the impact.

The vehicle's speed was set with the traction installation and measured independently with a photocell system positioned at 1 meter distance, figure 15.

Fig 14. Adapted braking system of the motor vehicle

Fig 15. Speed camera and photocells measuring the vehicle's speed

The speed cameras enabled us to record the impact with 1000 shots per seconds. The recordings' analysis showed a good correlation between simulation and real test. Following the impact between the bumper and the dummy's leg, the latter one suffered a fracture in the left knee. The software does not enable us to visualize the fractures; the fractures occur just as values of the contact forces. Consequently, a subsequent correlation of these values with statistically values obtained is required.

4.2 Pedestrian kinematics and dynamics during the impact

The experimentally obtained data and the researched casuistry show that the primary impact usually occurs at knee level, figure 16.; then, depending on the impact speed, at about 4 -10 ms the femur hits the engine's hood. At this moment the instantaneous rotation center moves to the contact point between the vehicle's hood and the pedestrian's femur.

The pedestrian rotation occurs in transversal plan. Concomitantly, the pedestrian's body and head are wrapped over the hood. At the second impact, the head hits the windshield or the hood, a series of factors being considered when establishing the impact point.

Among these factors we may mention:

- Frontal geometry of the vehicle;
- Impact speed;
- Pedestrian size;
- Position of the primary impact point to the pedestrian center of mass.

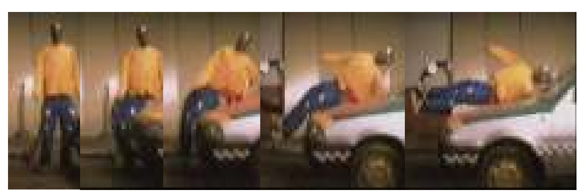

Fig. 16. Impact at 0, 50, 100, 150 and 200 ms

After the pedestrian has been hit by the vehicle in the femur region, it is noticed that at the beginning of the wrap phase, the pedestrian's upper body is maintained in vertical position, with arms close to the body, figure 16. Meanwhile, there occurs a relatively visible movement between the dummy's upper body and the front edge of the vehicle's hood.

The intensity of dummy's rotation depends on the impact speed. There occur rotations on all three axes traced through the dummy's body.

The secondary impact occurs in the windshield and hood region. The pedestrian hits the windshield with the head and for a short time, depending on the impact speed, the vehicle and the pedestrian form a common body; thus, the pedestrian has the same speed as the vehicle, being carried on the hood.

The experimental researches showed that for impact speeds of about 30 km/h, following the vehicle-pedestrian impact, the pedestrian becomes common body with the vehicle; the pedestrian is carried on the vehicle's hood until the vehicle comes to a stop and the pedestrian slides off the vehicle. The sliding may occur either laterally, due to the moment of rotation, around the vertical axis, imprinted to the pedestrian ever since the first contact with the vehicle, or in front of the vehicle. Data are confirmed by the casuistry studied by authors

The results resulted from experimental researches at low speed of the car, and the computer simulations are similar to Kuhnel-Schulz curvature and to the results provided by the specific casuistry. Therefore, for impact speeds of 30 km/h the pedestrian projection distance is of about 7 m.

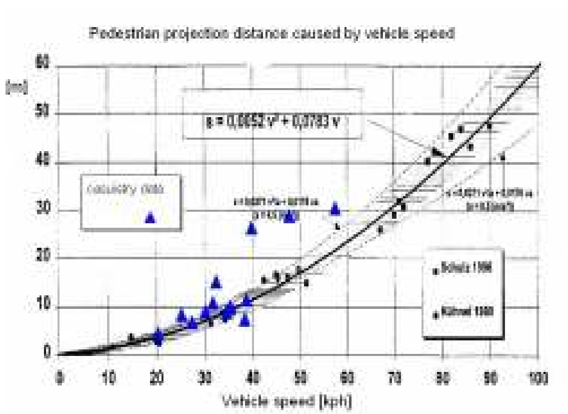

Fig. 17 Comparison between the Kuhnel-Schulz curve and authors studied casuistry

5 Conclusion

The analysis of the results obtained following the impacts suggests that despite the relatively low impact speeds, the head and thorax accelerations are significant; the duration at which these accelerations are present is added to these values. The injuries suffered by victims are serious and, most of the times, lethal. In the tests carried out, the values of the vertebral column accelerations were inferior to those given by the supportability limits of the human body. Therefore, during the experimental tests, at the initial impact between the motor vehicle and the lower limbs of the pedestrian, in the interval ranging from 0 to 60 ms, the mean value of the vertebral column acceleration was 9 g. In the interval ranging from 190 to 250 ms, when the pedestrian hit the windshield with the head, the mean value of the vertebral column acceleration is 12,75 g.

Between experimental tests and simulation there is a time lag of about 10% with regard to the moment the dummy's head hits the windshield. We believe that this difference results from the fact that on the real dummy the moments in the head-neck and hip-pelvis joints are constant during the tests, without having the possibility to modify these moments according to the relative angle between the body segments mentioned.

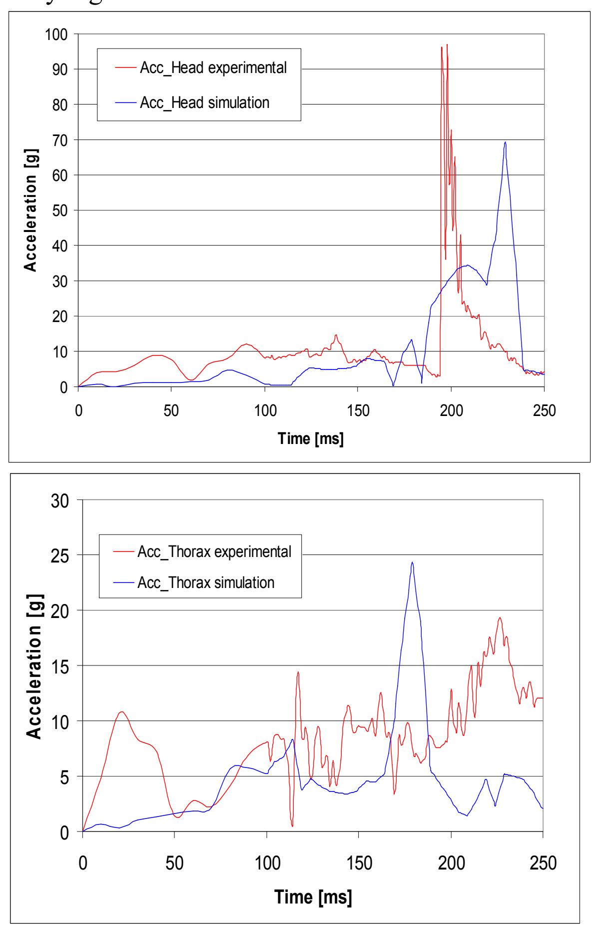

Fig. 18. Comparison between theoretical and experimental values

The maximum value of head deceleration is 95 g at 0,200 sec from the contact between the vehicle's bumper and the dummy's leg. Through the variation of moments of resistance in joints there was noticed an increase in the maximum values of head and thorax accelerations from the moment of the first contact until the moment the head hits the windshield or the hood.

By integrating the accelerations values obtained there are obtained the variation curves of speeds at which the pedestrian's head and thorax hit the vehicle's surface. The values obtained indicate a maximum level of the speed at which the head hits the windshield of 10,3 m/s at the moment of 0,2 sec from the beginning of the collision [2]. The values obtained are in concordance with the results obtained by other motor vehicles' manufacturers.

The secondary impact, with the soil, proved to be another important factor in generating severe traumas. Therefore, in the future, the efforts of motor vehicles' manufacturers should be oriented towards finding solutions that should diminish the effects of the collision with pedestrians, assuring, at the same time, protection to the vehicle's occupants.

In the last few years the EURONCAP Center - European New Car Assessment Program, a catalyst that encourages the design improvement for the new motor vehicles, has carried out tests whose aim is to analyze the degree of damage to pedestrians caused by all new models of motor vehicles. On the basis of EURO NCAP procedures new regulations regarding the protection for pedestrians are to be developed. Car manufacturers face a difficult problem because they must make a compromise between the protection for children and the protection for adults as the measures applicable for an adult are to be approached differently in case of children.

Another way to diminish the number of vehicle-pedestrian accidents is to create a road infrastructure that should meet the current requirements not only in urban areas but also outside urban areas (designing pedestrian walkway, avoiding the intersection of motor vehicle routes with the pedestrian ones, designing protection panels).

We also have to remind the fact that the road traffic education of each participant in traffic, driver or pedestrian, plays a major role in reducing the number of road traffic accidents.

References:

[1] SOICA, A., *Cercetari privind modelarea impactului autoturism-pieton /Researches into Modeling the Motor Vehicle-Pedestrian Impact/*. Doctoral Thesis, Braşov, 2002.

[2] TANASE, Gh., *Cercetări teoretice si experimentale privind optimizarea structurii fata in ceea ce priveşte siguranța pasiva a automobilului /Theoretical and Experimental Researches into Front End Structure Optimization concerning the Motor Vehicle's Passive Safety*, Doctoral Thesis, 2003.

[3] Dr. Steffan Datentechnik, *PC-Crash - operating Manual ver 8.0*, November 2006.

[4] NAHUM, A.M., MELVIN, J.W., *Accidental Injury*, Ed. Springer Verlag, 1996.

[5] HARTMUT, Rau., DIETMAR, Otte., BURKHARD, Schultz., *Pkw-Fussgangerkollisionen im hohen Geschwindigkeitsbereich Ergebnisse von Dummyversuchen mit Kollisionsgeschwindigkeiten zwischen 70 und 90 km/h*, Journal Umfall und Fahrzeug technik, Decembrie 2000, page 341-346.

[6] ARTRI. Asociatia Romana pentru Transporturile Rutiere Internationale. Raport circulatie rutiera 1991-2002.

[7] Traffic Injuries of Pedestrians - Estimate of Speed of Collision of Vehicle with Regard to Quantity of the Pedestrian's Injury. http://www.nemcb.cz/soudni/acitace.html.

[8] European Road Accident Database (CARE), EU, http://ec.europa.eu/transport/roadsafety/road_safety_observatory/care_en.htm.

[9] National Highway trafic Safety Administration (NHTSA), USA. http://www.nhtsa.dot.gov

[10] COUNTRY REPORTS ON ROAD SAFETY PERFORMANCE, ROMANIA, WORKING GROUP ON ACHIEVING AMBITIOUS ROAD SAFETY TARGETS, OECD, aug. 2006.