ASPECTS REGARDING THE ANALYSIS OF THE CAR GEOMETRY INFLUENCE OVER THE PEDESTRIAN INJURY SEVERITY AND DISTRIBUTION

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ABSTRACT

Worldwide, the road traffic accidents resulted injuries represent one of the top major factors to reduce life expectancy. Statistical analysis reports show that, while the general trend in some industrialized regions is to reduce the effects of traffic accidents by the means of imposing programs involving the car manufacturers, the research institutions and the society (i.e. APROSYS and PReVENT for E.U.), for the regions under development there is room for improvement in this area. In example, for E.U. member state Romania, the percentage of pedestrian casualties of all road traffic victims not only surpasses several times the mean value for the European Union, but is also having an increase trend, thus creating the need for developing new solutions in the field of pedestrian protection, or improving the ones that are already taken into consideration.

When regarding the vehicle to pedestrian accident from a systemic point of view of a Haddon matrix, the frontal body design can be identified crossing the vehicle as factor with the main collision as event phase. Along with other body design components, the vehicle frontal geometry plays an important role on the dynamics and outcome of traffic accidents involving pedestrians. The manuscript outlines the connection between the variation of several vehicle geometrical parameters and the injury severity and its distribution on pedestrians.

KEYWORDS: safety, pedestrian, impact

INTRODUCTION

Road traffic accidents make up for a financial cost of about anywhere between 1% and 2% of a country's GDP – less for underdeveloped countries and more for industrialized countries. DALY figures show that traffic accidents resulted injuries, situated in the top of factors responsible to reduce life expectancy on 9th place, are estimated to rise up to 3rd place towards 2020. According to the last WHO/Wold Bank report on this matter, globally, traffic accidents represent the 2nd death cause for children and youth between 5 and 29 years old and 3rd for the adult age group (30-44 years old). The figures on victims of road traffic accidents sum about 1.2 million persons per year, while for injured, up to 50 million persons. Resumed as a daily report, the number surpasses 3000 deaths, about ¾ of which found in countries under development.

On the local (Romanian state) level, as can be seen in figure 1, the probability of death as a pedestrian hit by a car is by far greater than for the European Union. Several factors such as the quality of road infrastructure, the level of law enforcement and specific educational programs are the major contributors to this situation.
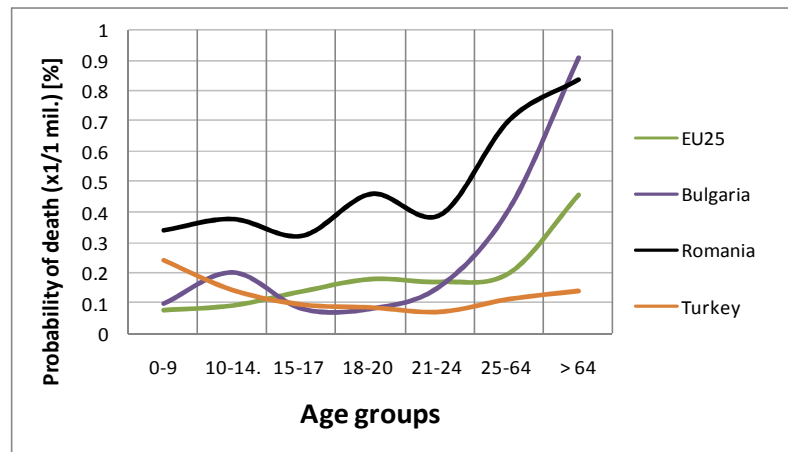

Fig. 1 Probability of death by car accident as pedestrian

Based on data such as this, the need of related studies, as the ones referring to the frontal car design – pedestrian connection, is considered as a common sense step in any possible pedestrian protection related project.

VEHICLE-PEDESTRIAN CRASH ANALYSIS

A clear schematic view – based here on a typical Haddon matrix - of the factors and collision phases of a vehicle-pedestrian collision analysis outlines the frontal body profile at the intersection of vehicle as factor and main collision as phase. The body profile has a great influence on the main impact areas, the impact dynamics and the outcome translated in the degree of injuries sustained by the pedestrian. It has currently several classifications, one of them being proposed by the recent European Integrated Project - APROSYS. These classifications use the notion of geometrical corridor in order to

determine a vehicle's profile class, notion which is based on basic geometrical parameters, such as bonnet leading edge height, bumper height, bumper lead and more.

Phase	FACTORS		
	Human	Vehicle	Environment
Before collision	Alcohol, fatigue, absence of mind	High speed	Crossroads, poor lightning, pedestrian crossings, poor legislation enforcement
Collision	Osteoporosis and other bone structure problems	Frontal body profile	Road characteristics, speed limits
After collision	First aid	Forensics	Ambulance service swiftness, healthcare system, trauma care

Based on the car-body shape, classified into geometrical corridors, various acceleration curves can be expected for the pedestrian.

In order to evaluate the degree of injury for the human body, several classification criteria have been used, for the body as a whole, or specialized for different regions, criteria such as AIS or HIC.
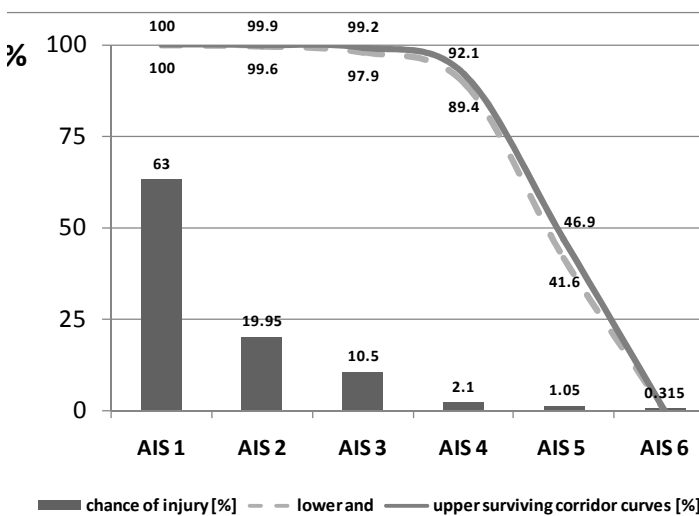

Fig. 2 Likelihood of injury severity and survival corridor based on AIS for a pedestrian hit by a vehicle
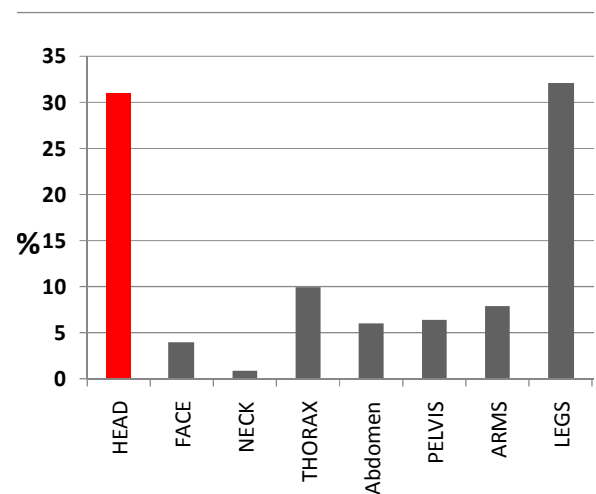
Fig. 3 Localization of injuries for a pedestrian hit by a vehicle

When considering the probability of injury localization in case of a vehicle-pedestrian accident, it can be seen that the head, the legs and the thorax are more likely to sustain injury.

MATHEMATICAL BACKGROUND OF THE MULTIBODY PEDESTRIAN MODEL

The multi-body pedestrian mathematical models – including the one used for the simulations here - are based upon the Lagrange multipliers. The Lagrange theory postulates that if there are $[b]^T[x] = 0$ and $[A][x] = 0$, there must be a vector [λ], called Lagrange multipliers vector, so that: $[b]^T[x] + [\lambda]^T[A][x] = 0$, where [b] is a constant, n-dimensional vector, [A] – a constant m*n matrix, and [x] - a variable vector.

Applying this theorem for the relations:

$$\left([m][\ddot{q}] - [Q] \right)^T [\delta_q] = 0, \ [J][\delta_q] = 0 \text{ leads to:}$$

$$\begin{bmatrix} m & J^T \\ J & 0 \end{bmatrix} \begin{bmatrix} \ddot{q} \\ \lambda \end{bmatrix} = \begin{bmatrix} Q_{ex} \\ \Psi \end{bmatrix} \tag{1}$$

where [J] is the restriction Jacobin.

Solving this equation leads to simultaneous determination of system accelerations and Lagrange multipliers. By using the method of partitioning the generalized coordinates, one can transform the ADE (algebraic - differential equation) matrix equation into the partitioned parameters form:
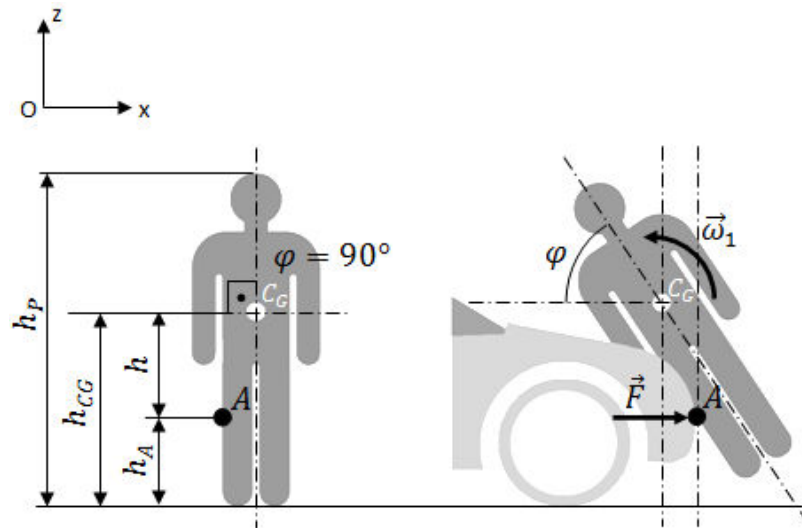

Fig. 4 Single-body model

For a rigid body, using the formula for solution stabilization, we can determine the differential movement equation for the independent generalized coordinate φ_1:

$$\left(I_1 + m_1 h_1^2 \right)\ddot{\varphi} - M_1 + h_1 m_1 g \cos(\varphi) = 0 \tag{2}$$

SIMULATION

Accident reconstruction software has been used for simulating the impact behaviour and collision mechanics for several test series. The vehicle model has been assimilated to a rigid body, geometrically shaped by the basic parameters previously mentioned. The 20-body model offered by PC-CRASH 8.0 was considered to be sufficiently accurate for these simulations.

During the simulation, a number of eight parameters, responsible for the frontal vehicle geometry, have been varied in order to determine the car-body influence on the impact dynamics, parameters such as bumper height, bumper lead, bonnet leading edge and bonnet and windscreen geometry.
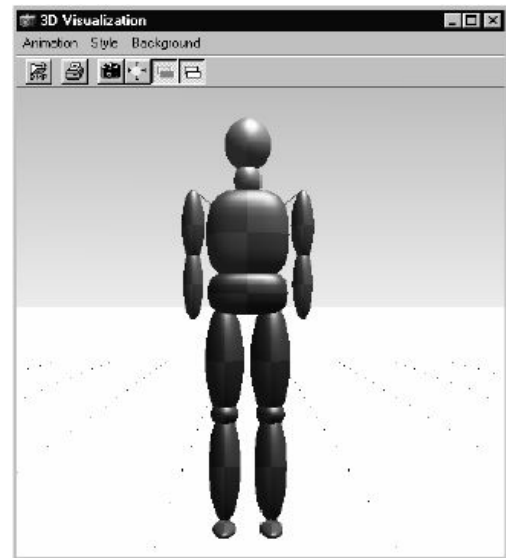

Fig. 5. PC-Crash multi-body model

Table 2 Sample input values for a simple 5 values test

Parameter no.	Parameter description	Value 1 [m]	Value 2 [m]	Standard value [m]	Value 4 [m]	Value 5 [m]
P1	Lower bumper hight	0,25	0,30	0,35	0,40	0,45
P2	Upper bumper hight	0,40	0,45	0,50	0,55	0,60
P3	Bonnet leading edge hight	0,71	0,76	0,81	0,86	0,91
P4	Lower windscreen edge hight	0,86	0,91	0,96	1,01	-
P5	Bumper lead	0	0,02	0,05	0,08	0,10
P6	Bonnet leading edge lead	0	0,02	0,05	0,10	0,15
P7	Bumper mount height, relative to standard value	-0,10	-0,05	Standard value	+0,10	+0,20
P8	Bonnet leading edge position, relative to standard value	-0,05	Standard value	+0,05	+0,10	+0,20

Varying the bumper width was obtained by varying P1 and P2 parameters, varying the bonnet angle was obtained by varying P3 and P4. The intention for varying P7 parameter was to mentain constant the bumper width.

For one of the tested situations, the chosen representative vehicle speed was 30 km/h, while simulating a pedestrian movement speed of 3 km/h. The pedestrian was placed front-right facing an axis perpendicular to the vehicle movement axis / road axis, expecting the impact from his right side.

The resulted acceleration graphs and data have been used to analyze the influence of the chosen parameters on AIS and HIC levels.
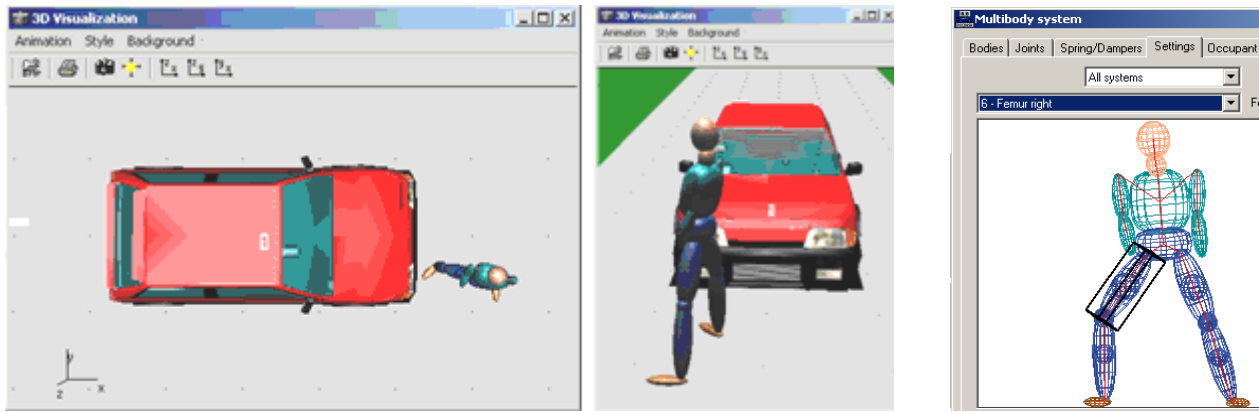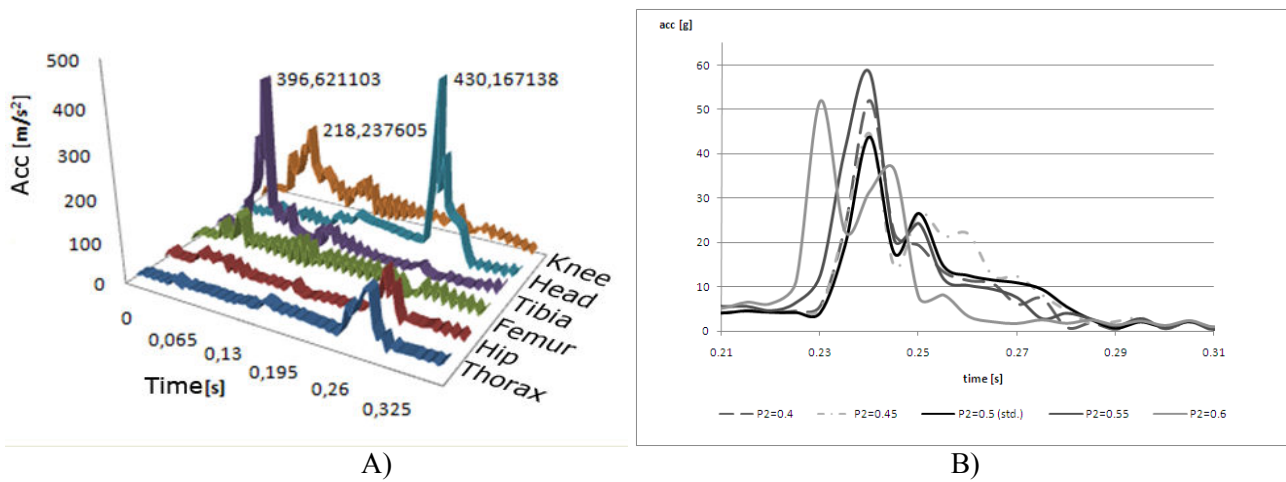
Fig. 6 Virtual tests setup

A)

B)

Fig. 7 A) Sample accelerations for various pedestrian impact regions. B) Sample head accelerations for varying the second parameter
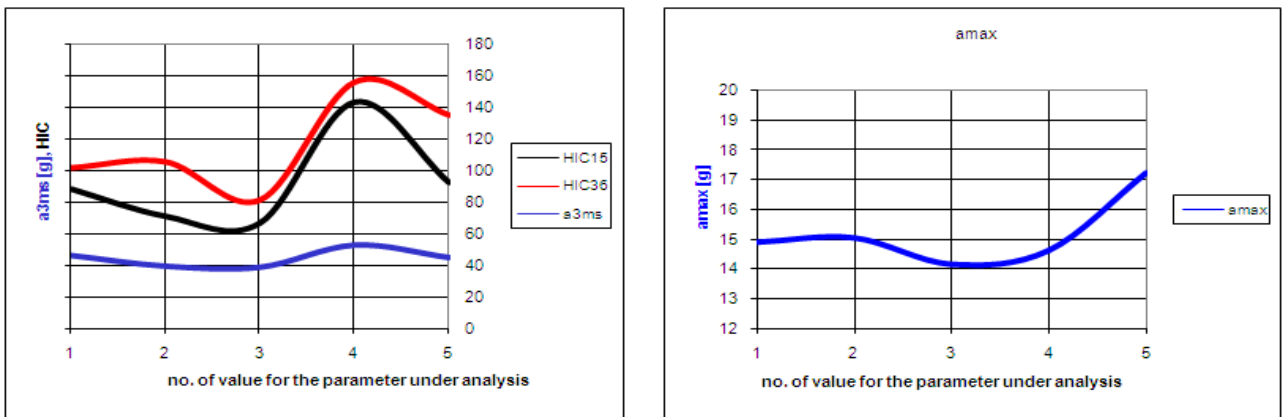

Fig. 8 Sample results for varying parameter 2

In figure 8 shows a sample of simulation results obtained by modifying the second parameter. Here, there have been analyzed the maximum acceleration for 3 ms and the biomechanical solicitation embodied by HIC15 and HIC36. The lowest HIC value can be obtained for the 3rd value of the parameter at an acceleration of 44 g. This is not a critical value. Lowering the value increases the load on the pelvis, femur, tibia and knee. Increasing the value leads to increasing the load on the thorax.

VALIDATION

For the validation tests, the dummy was placed in front of the vehicle, simulating a road crossing. For the test presented below, the impact took place in the tibia region, right below the knee. The vehicle impact speed was close to 29 km/h, the dummy hitting the vehicle between the first third and the median line of the bumper.
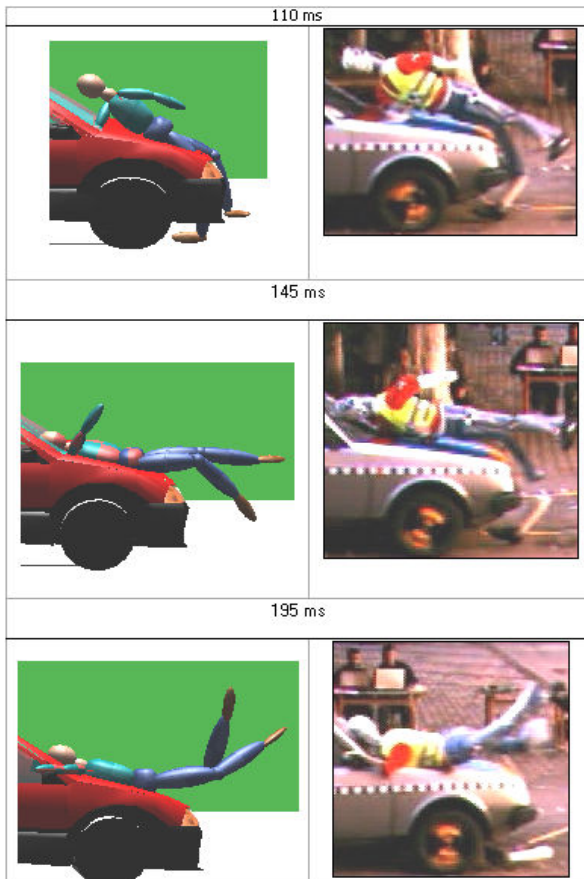

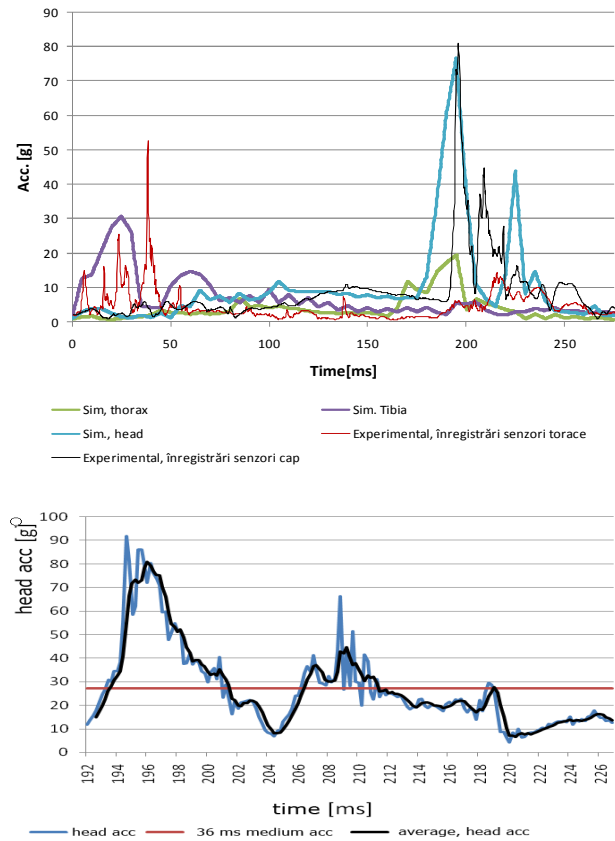Fig. 9 Overlapping sequences

Fig. 10 Overlap of simulation and real tests accelerations (up) and HIC36 results (down)

From the diagrams analysis, it was determined that the impact took place at 29 km/h for a duration of 250 ms. The dummy was projected into the windscreen head-on. The first leg to impact the vehicle broke loose from the joint area, the joint being constructed to sustain forces up to 6500 N. The medium acceleration recorded had a value of 4.57 g for the thorax and 6.96 g for the head, respectively. The recorded data analysis also outlines that, because of the right arm positionning and trajectory, the arm impact with the bonnet reduced the upcomming thorax impact level with the bonnet. Other dummy regions directly involved in the collision were the pelvis right side and the superior region of the upper leg, both in contact with the bonnet leading edge area. The maximum impact force between the bumper and the pedestrian leg appeared after about 10 ms, the effect of which was breaking the dummy leg. The maximum acceleration registered at impact was at the moment of contact between the head and the windscreen at 195 ms from the impact initialization.

CONCLUSIONS

Of the conclusions derived from the study presented above:

- The biomechanical maximum head stress results for the 5th variation of the parameter: bumper lead, where it was obtained a value HIC15 of 250. A reduction of HIC can be observed for all variation of 2nd and 3rd parameters;

- Analyzing the collision at head level, it was possible to observe that the head to windscreen impact lasted for about 90 ms, with a maximum acceleration value of 810 m/s2, a HIC15 value of 133,35 for a medium acceleration of 379,81 m/s2, and a HIC36 value of 139,32 for a medium acceleration of 272,32 m/s2

- The optimization of the analyzed parameters can lead to a greater impact in the decreasing of the collision speed influence on the pedestrian injury level, most notably quantified with HIC, thorax acceleration and other means.

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