Vehicle speed correlation with deformation amplitude due to adult pedestrian impact in car traffic accidents

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Abstract In many cases due to braking equipment (ABS) or for other reasons braking marks can not be revealed at the crime scene in pedestrian traffic accidents. So in order to estimate the impact speed of the vehicle with the pedestrian body the specialists must use alternate methods. One of this method is based on comparing the amplitude of damages of questioned vehicle with damages produced at known speeds. One of the important pieces which is damaged in frontal collisions with pedestrians is the wind screen. In this paperwork is shown that the amplitude of windscreen damages allows to estimate the impact speed with a precission of plus minus 5 km/h between 50 to 120 km/h in frontal collisions with adult pedestrians.
***Keywords*:**A speed , impact, pedestrian, traffic accidents

1. Introduction

1.1. Wind screen

The windows of a common vehicle must ensure a good visibility and have to comply to insurance quality standards meaning that in case of crash the damages or injuries to be reduced at minimum.

The injury danger which may occur are due to glass fragments formed after crush. The injuries might aggravate the accident result.

In order to reduce this dangers which can affect the car occupants or pedestrians or other persons who are involved in or after the accident is produced the fabricant and designers developed technological processes.

Now different kind of glass and windows are used in different montage solutions which are responding to quality standards and security standards too.

After the type of glass used two large windows categories are distinguished:

- **securrized window** – realized from a single glass sheet. After the glass sheet is obtained it is thermo treated until a vitrify consistence is obtained and traction forces are cross applied both vertical and horizontal directions and after that a special cooling process is follow. This combined treatment, mechanical and thermal insures a greater mechanical resistance at impact and vibrations. Glass securrized sheets don’t allow cutting so the window must be created at the desired dimensions from the beginning. When a force is applied the resistance is greater that in ordinary glass case but when a limit point is touched the entire sheet is fragmenting in thousands of little parts. This disadvantage is very benefic in case of accident when the window is crushed eliminating the risk of cutting injuries.

- **stratified window** – is realised by adding at least two glass sheets glued with a lamina plastic foil glued together. The glass sheets might be normal or securized.

The wind screens are made in different solutions but most frequent are made by two glass sheet glued with a lamina plastic foil between them and a securized sheet is oriented inside the vehicle. The special vehicles used for VIP protection or for great values transporters the thickness of windows is between 5 to 10 cm with multiple stratification and securized glass sheets so it can resist at three bullet shootings from short distances with calibre 4 to 7,62 mm. In such situations this windows ca be a serious obstacle and major injuries might occur in case of head or side impacts this windows being a solid, rigid and not deformable barrier.

In order to increase the driver and passenger protection the car fabricants adopted a glued fixation of windscreen instead of gasket fixing method. So in case of impact of the head with the windscreen the windscreen will unglue and will be projected in outside. This fixing method will avoid the injuries of the neck or cervical region.

1.2. Windscreen testing

Tests are made with a bowl hard essence wood made 190 mm diameter, coated with a thin hair felt coat and covered with synthetic skin having total weight of 2260 g, is dropped from 4 m height on

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square samples of 300 x 300 mm, the windscreen will comply if the surface will not suffer significant damages as amplitude [1] and the bowl will remain at least 5 seconds on the surface of contact. After this period under its own weight the wood bowl press the lamina plastic foil until it will brake.

European Experimenting of Vehicle Committee (EEVC) proposed and elaborated procedures and testing methods for injury evaluation suffered by victims of vehicle impacts.

For tests were made models for superior and inferior part of the foot, pelvis and head [2]. Artificial head is made in two variants, for adults and children.

For adults this is a aluminum sphere with 140 (105 child) mm diameter covered on a half of surface with synthetic skin (vinyl type) of 12,5 mm thickness. Gravity centre of sphere including measuring data devices, is in the middle with a deviation of ±10 mm (fig. 1.2.1).

Experimental data can be obtained by hitting of test surface with artificial head in free drop (drop test) or by pendulum from a chosen height in order to obtain a speed in momentum of impact (fig. 1.2.2).

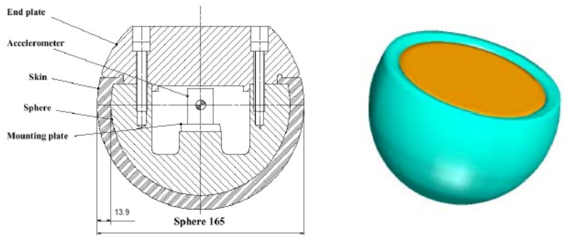

Fig. 1.2.1. Artificial head model

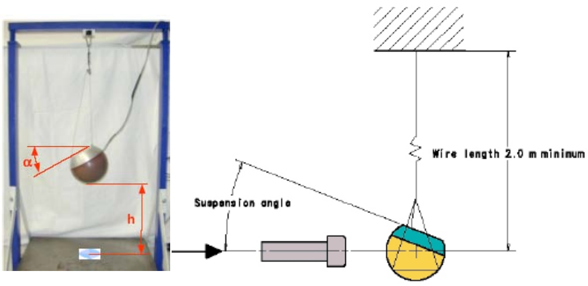

Fig. 1.2.2. Drop test and pendulum test

1.3. Mathematical modelling of contact between vehicle and pedestrian

For mathematical modelling of pedestrian – vehicle impact the Japanese specialists Yang and Kajzer [4] realized a multibody dummy using statistical data obtained by analysing pedestrian – vehicle accidents produced in Japan [6]. Adult pedestrians involved in car accidents are 140 – 165 cm height and a weight between 55 – 65 kg. By calculations was obtained a dummy model used for tests (fig. 1.3.1).

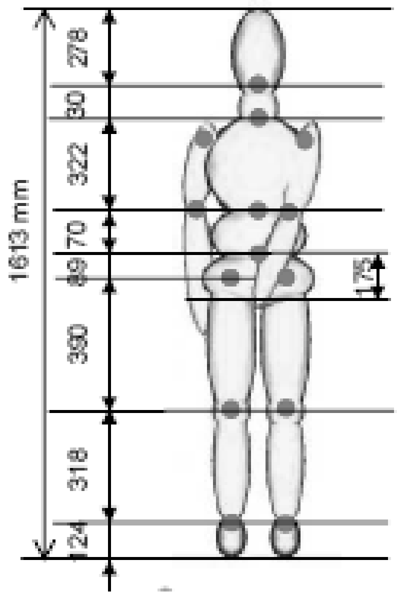

Fig. 1.3.1. Dummy model

part of body	Mass (Kg)
head	4,7
neck	1,1
chest	14,7
abdomen	3,4
pelvis	9,7
upper arms	3,2
lower arms	3,6
upper legs	11,9
lower legs	5,5
feet	1,3
Total	59,0 kg

1.4. Impact producing mode

From experimental data using dummies and cases studies in reconstruction of accidents with pedestrians, was noticed that at speeds under 40 km/h the pedestrian is struck with bumper and rolled on hood edge.

After this speed, the pedestrian hits the hood and front windscreen with the head. Greater speed is, upper zone of windscreen is the contact with head. The distance from the head struck and lower edge of windscreen depends on the height of victim and shape of the front part of the vehicle. It was noticed that the deformation amplitude of the struck zone increase with speed value too.

A large quantity of energy is absorbed by the hood and bumper (fig.1.4.1). The deformation of bumper and hood increase with energy absorbed so the designers were take in consideration easy deformable structures in order to increase the pedestrian protection [5]. In this situations the stuck head zone is reduced considerably.

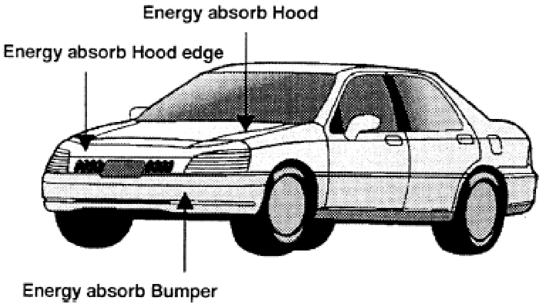

Fig. 1.4.1. Front parts of the vehicle were the most of energy is discharged

The distance from the front hood edge of the struck head depends on speed, weight and speed too. Very important is the mode of pedestrian displacement, walk, run, rush and so on. The mode of the vehicle displacement because during the bracking period the front bumper is lower with appreciatively 150 mm. In fig. 1.4.2. is shown a graphic for dependence of pedestrian height of wrap around distance (WAD) obtained during the tests with dummy at impact speed of 40 km/h [3].

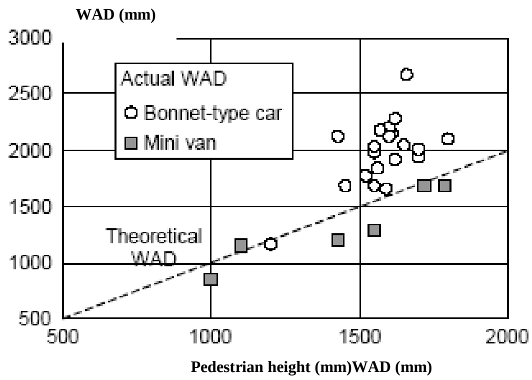

Fig. 1.4.2. Pedestrian height and WAD

During impact pedestrian kinematics involve both translational and rotational movements. At impact speed of 40 km/h, the pedestrian's upper body rotates against the vehicle and this movement is dominant at mini or medium sedan cars. whereas a mini van the translation movement is dominant and the pedestrian is pushed forward in front of the vehicle as shown in fig. 1.4.3.

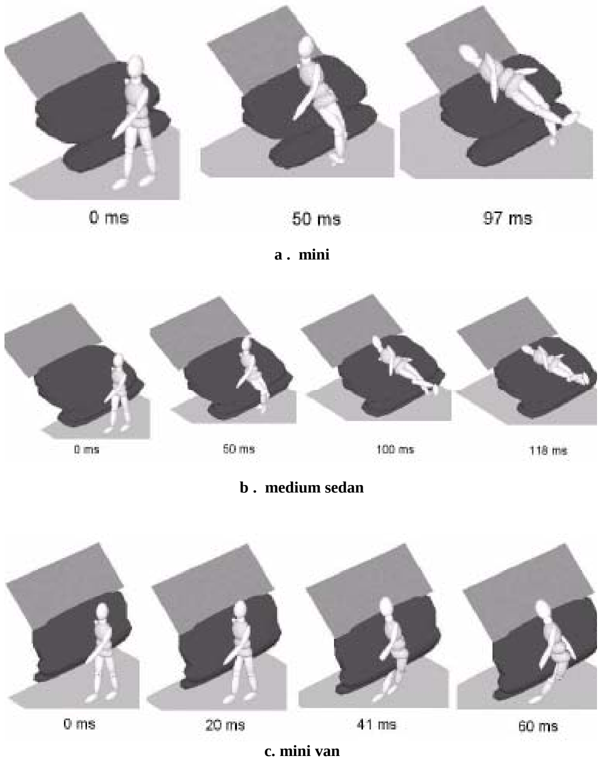

Fig. 1.4.3. Pedestrian kinematics: a . „mini"b . medium sedan, c . mini van

The head's resultant impact velocity relative to the vehicle is compared among three types of vehicles (fig. 1.4.4). Because the translational movement dominates pedestrian kinematics in a mini van impact, the resultant head velocity decreases consistently after impact. The head contacts the vehicle at 9.4 m/s which is lower than initial velocity. In case of medium sedan and the mini car, and the mini car, the influence of both translational and rotational movements is significant. In the first phase the resultant head velocity increases due to the rotational movement of the upper body, then decreases due to the translational movements of the whole body. The head's resultant velocity on impact is 12.0 m/s for a mini car and 9.6 m/s for a medium sedan . It is clear that the resultant head velocity depends on the shape of vehicle (fig. 1.4.4).

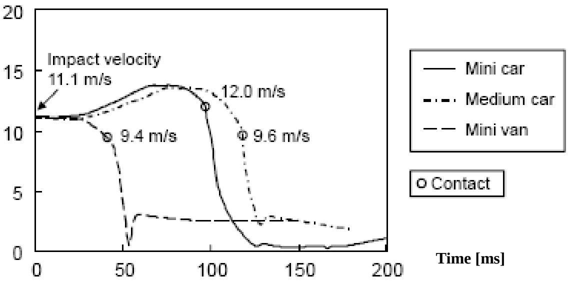

Fig. 1.4.4. resultant head velocity to the vehicle

1.5. Head impact tests

The adult headform impactor proposed for tests in EEVC [7] is made by a sphere with mass of 4.8 kg, covered with artificil skin. The acceleration is measured in the center of gravity. The impact angle is 65 degrees and speed was 40 km/h.

The windscreens used were made from three components: a sheet of securized glass 2.3 mm thickness, a plastic lamina foil PVB (polyvinylbutyral) of 0.76 mm and another sheet of normal glass 2.3 mm.

The struck of windscreen and amplitude of obtained deformations was registered in four different points: near to base of frame's windscreen, (fig. 1.5.1), 5 cm above, (fig.1.5.2), 15 cm above (fig. 1.5.3) and in the middle (fig. 1.5.4)

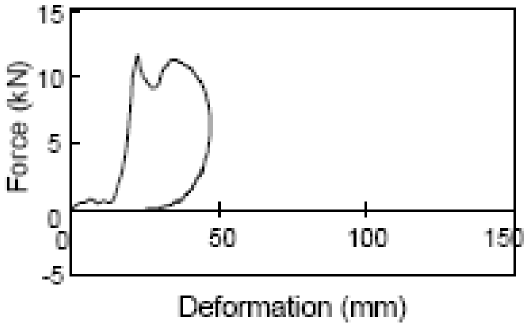

Fig. 1.5.1 Lower windscreen frame

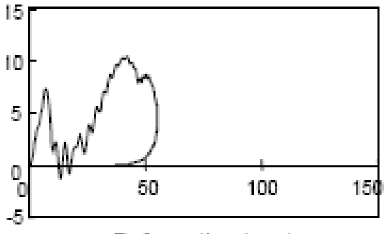

Fig. 1.5.2 50 mm Lower windscreen frame

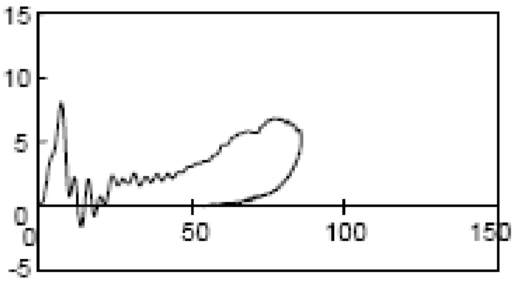

Fig. 1.5.3 150 mmLower windscreen frame

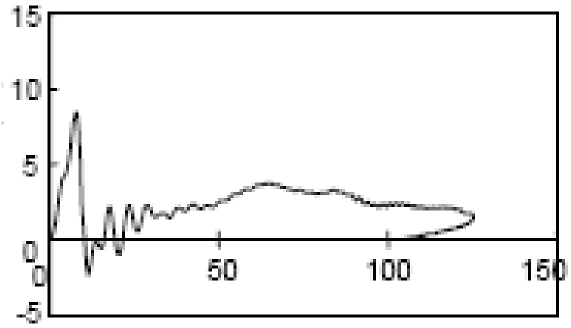

Fig. 1.5.4 middle of windscreen

2. Experimental

2.1. Head Injury Criteria and dynamic deformation

The deformation necessary to keep the HIC bellow 1000 is important in order that a car to be designed to reduce the head pedestrian injuries. MacLaughin et al. [8] showed in head impact tests onto the hood top (velocity at 37 km/h) that the HIC is related to the dynamic deformation. This study can be extended on impact of head with windscreen.

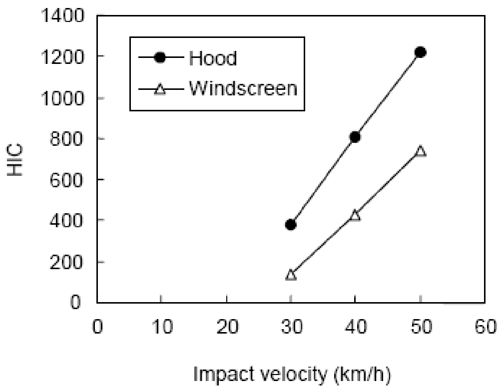

Fig. 2.1.1 Effect of impact velocity on the HIC for tested car

The hood produces a linear increase in the HIC with increasing impact velocity, and the HIC value exceeds 1000 at 50 km/h. When impact velocity is 50 km/h on the windscreen, the interlayer was torn(there was no penetration of the head form), which results in a HIC value below the injury threshold. The fragments of broken glass become larger with higher impact velocity (fig. 2.1.1). Since the HIC value for impact with windscreen is still less than the injury threshold even at the impact velocity of 50 km/h, it is considered the injury risk to the head is low in the center of the windscreen.

2.2. Theoretical HIC

Examining the relation between the HIOC and dynamic deformation based on the approximation of acceleration curve it can be assumed that deceleration time of headform will be a curve (Fig. 2.2.1) of the second degree of time *t*:

$$\alpha_{(t)} = -a \cdot t(t - 2t_0) \qquad (1)$$

where “a” is the coefficient of curve fitting and t_0 is the time when deceleration reaches maximum.

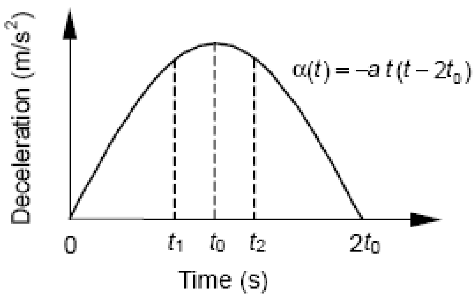

Fig. 2.2.1. Headform deceleration

We can calculate the HIC as follows:

$$HIC = \max_{0 \le t_1 \le t_2 \le 2t_0} \left[\left\{ \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \frac{\alpha(t)}{g} dt \right\}^{2.5} (t_2 - t_1) \right] \qquad (2)$$

where g = 9,81 m/s^2

assuming $t_0 = (t_1+t_2)/2$, introducing variable $\tau = t - t_0$, the HIC can me computed as follows :

$$HIC = \max_{0 \le t_1 \le t_0} \left[\left\{ \frac{1}{t_1} \int_0^{t_1} \frac{a(\tau^2 - t_0^2)}{g} d\tau \right\}^{2.5} (2t_1) \right] = \qquad (3)$$

$$= \sqrt{2} \left(\frac{5a}{6g} \right)^{2.5} t_0^6 \qquad (4)$$

Finaly a relation between HIC and dynamic deformation x_d(m) is obtained as follows:

$$HIC = 2^{-9} 3^{1.5} 5^{2.5} g^{-2.5} v_0^4 \, x_d^{-1.5} = 0.001882 \, v_0^4 \, x_d^{-1.5} \qquad (5)$$

where v_0 is the initial velocity (m/s). This parameter is the theoretical HIC and increases with v_0 and decreases with dynamic deformation $x_{d.}$. The HIC value is below 1000 if:

$$x_d > 0.0934 \text{ m}$$

2.2. Reported cases in reconstruction traffic accidents.

The theory and mathematical models of ca – pedestrian impacts were validated practice in traffic accident reconstruction. So it was easy to notice that exist a dependence between velocity of impact and amplitude of windscreen deformations.

At velocity between 40 and 50 km/h the dynamic of pedestrian shows a stuck with front bumper and front edge hood but doesn’t hit the low frame of windscreen. If the height of victim is greater than 1.7 m then it is possible to appear a stroke between the head and lower part of windscreen. If the car is in braking process then the victim is rolled on hood and pushed out in a side of vehicle (fig. 2.2.1).

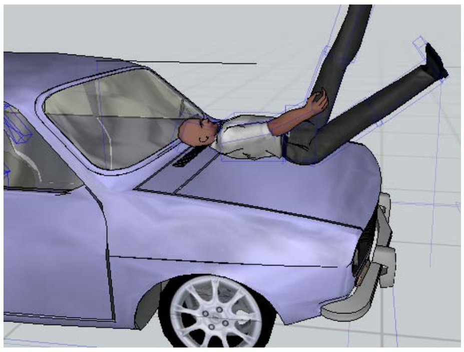

Fig. 2.2.1. Dynamics of pedestrian impact at 40 - 50 km/h

As shown in fig. 2.2.2 an impact with pedestrian produced at 48 km/h with a Dacia 1310 vehicle. Notice that the victim stroked front windscreen at the lower base but the amplitude of deformation is under 30 mm deep.

Fig. 2.2.2 Impact at 48 km/h velocity with adult pedestrian and Dacia 1310 vehicle

At higher speeds the amplitude of deformation increases in depth with velocity and the distance from the base of windscreen increases too. The dynamic of impact shows a significant damage of windscreen.

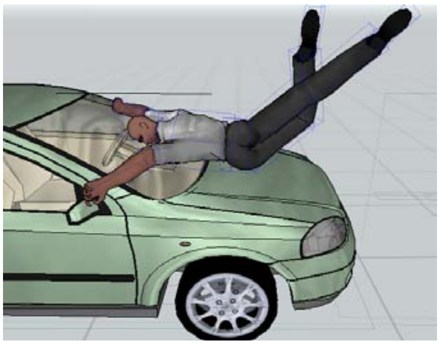

Fig.2.2.3. Dynamic of impact at 60 – 70 km/h with adult pedestrian

At high velocity than 70 km/h the intermediate lamina plastic foil broke.

Fig.2.2.4. Impact at 68 km/h velocity with adult pedestrian and Opel Astra vehicle

At speeds over 60 km/h a little damage of the hood and only the front bumper and front edge hood suffered damages but the wind screen is more damaged the amplitude being increased with speed, see in fig. 2.2.4 the aspect of damages at 68 km/h with an Opel Astra vehicle and adult pedestrian. Amplitude of deformation was 920 mm depth.

Over 70 km/h the energy of impact is discharged more on front windscreen so the amplitude of stroke is higher and intermediate lamina plastic foil broke. (fig.2.2.6).

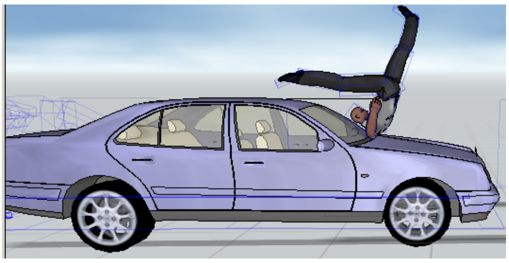

Fig.2.2.5. Dynamic impact at 60 - 80 km/h velocity with adult pedestrian

At high speed the pedestrian is projected on the upper hood and stroke zone is large (fig. 2.2.6). In such cases the lower leg part can be detached on the rest of the body and injuries are very severe.

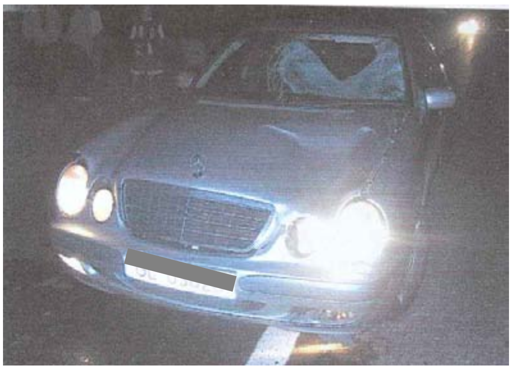

Fig.2.2.6. Impact at 118 km/h velocity with adult pedestrian and Mercedes Benz E Classe

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