EXPERIMENTAL STUDY OF THE VEHICLE-PEDESTRIAN COLLISIONS

[1]Dragoş Dima, [2] Florin Ruşitoru, [1]Adrian Şoica, [1]Stelian Ţârulescu

[1] Transilvania University of Brasov, Romania; [2] National Institute of Forensic Expertise, Bucharest, Romania

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ABSTRACT - The paper describes the way a vehicle-pedestrian collision process takes place, aiming to a better understanding of the phenomena that appear within the dynamic of this kind of road events.

The aim of this study was to determinate the acceleration and speed value of head and thorax from pedestrian involved in accident. Analyzing these values can contribute to a better way to solve the dynamics of the accident and also to improve the passive safety.

INTRODUCTION

Worldwide, pedestrian crashes constitute the most frequent cause of traffic-related fatalities. The head, in approximately 60% of the cases, is the most frequent area of injury in pedestrian fatalities [1], and the vehicle area causing these injuries most often is the bonnet. Therefore a lot of pedestrian dummy tests were conducted, the applications made in this field including the study of pedestrian kinematics, injury prediction, or the evaluation of countermeasures including active systems. As a result of studies on injury mechanisms, tolerance levels and influences of the vehicle design on impact responses, the impact speed and vehicle front structures including geometry and stiffness have been shown to be important injury-producing factors [2].

TESTING METHOD AND MEASUREMENT EQUIPMENT

The tests were conducted in the Passive Safety Laboratory at S.C Automobile Dacia-Renault S.A. Pitesti. In order to define the tests there were considered as representative for pedestrian-vehicle accidents the following two situations: 1 - pedestrian in lateral position (crossing the street), hit with the frontal part of the braking vehicle; 2 - pedestrian heading the vehicle, suffering frontal hit by the vehicle having a constant speed.

Vehicle speed at time of impact was approx. 30 km/h. To conduct the tests the following equipment was used: power sources and specific accessories specific to collision testing; Dacia Nova vehicle prepared for collision and equipped with two Hybrid II humanoid dummies; braking system mounted on the vehicle; hydraulic drive sled system (collision circuit, traction installation, traction cable, vehicle designed traction sled, traction sled unlocking damper, cone-shaped key unlocking system, traction cable locking); lighting system for fast filming (1000 frames/sec); high speed cameras with a speed of 1000 frames/sec and an electronic synchronization system of the simultaneous or decaled start of the fast filming cameras; speed measurement system; two photocells for automatic starting of filming cameras, one for the collision data acquisition installation recording system and one as a trigger signal for the magnetic tape recorder; collision data acquisition cables; two triaxial accelerometers; collision data acquisition installation; software for analyzing and processing signals and images filmed at 1000 frames/sec; pedestrian dummy.

EXPERIMENTS PREPARATION

According to the description in [3,4] the pedestrian dummy was 73 kg weight and 180 cm height and was conceived to have 11 body segments, which corresponds to the anthropometry of a 50th percentile male adult [2]. The dummy has been modified in the Passive Security Laboratory Pitesti by adjusting a Hybrid II dummy head to it, equipped with an accelerometer, mounted in its center of gravity. In order to better fasten the dummy’s head, modifications were made to bind it in three points, on the shoulders and spine respectively. A second similar accelerometer was mounted on the spine of the dummy, in order to measure the acceleration at thorax level. The accelerometers were mounted with their axes parallel to the three anatomical planes of the body

Figure 1. Accelerometer, mounted in head’s CG (left). Dummy's head (right)

The vehicle was prepared for collision and equipped with two humanoid dummies Hybrid II. The braking system was mounted in the hood. The test vehicle was a Dacia Nova, with a weight of 1024 Kg and its fuel tank empty. The frontal area and the hood were painted to differentiate the zones with different pedestrian harming potential, and to facilitate the software image analysis.

Figure 2. Weighing the test vehicle equipped with two humanoid dummies Hybrid II. (left) Breaking system mounted on vehicle (right)

A special electric cable triggered breaking system was mounted in the trunk of the car. It's purpose is to trigger the break on the vehicle at the moment of impact with the pedestrian dummy, and avoid destroying it by impact with the fixed collision barrier (170 tons + mechanic – welded block for delayed collision) situated at approx. 15 meters from the impact area.

The high-speed video system comprises two digital cameras with a speed of 1000 frames/sec and an electronic synchronization system of the simultaneous or decaled start of the fast filming cameras. These cameras were positioned for filming from above and left side points of view. The necessary lighting level was obtained using 30 lamps with 1 KW light bulbs each. 20 lamps were positioned laterally and 10 were positioned for above lighting. Starting the cameras is done using special synchronization and simultaneous start-up installations. Because the film roll being used is 30 m long, and the camera needs an acceleration period, an effective filming time of approx 1.5s is obtained. A badly timed handling results in a failure to study the desired phenomena at high speeds. The cameras being used allow for filming speeds of up to 10000 frames/sec, but this requires very fast phenomena and very special lighting. The measurement system of the velocity was measured using a speedometer made up of two electric photocells for camera automated starting, one for the recording system of the data acquisition installation at collision and one trigger signal for tests recorder. The measurement precision was 0.1%, the distance between the two photocells being 1m.

The data acquisition installation at collision was designed for 56 measurement channels with three analyses possibilities: general visualization on VU-meters with led's indication possible malfunctions on channels; ultrafast recorders with ultra violets; numerical recording on special magnetic-tape recorder with 56 tracks

The installation is made up of three constructive blocks containing gates, amplifiers, SAE filters, analogue/numerical conversion and deconversion modules, magnetic-tape recorder, automation, starter, collision blocks, damages alarms and protections, UV recorder. When using the signals recorded by the magnetic-tape recorder there is made use of apparatus of type "magnifier times" corroborated with the severe reduction of magnetic-tape recorder speed. The decelerations occurring at the moment of impact between the vehicle and dummy are measured on the three directions of the reference system considered (for vehicle XX', YY', ZZ'). The electric links between accelerometers and data acquisition installation, the coding, and the recording were conducted through cable containing 10 independent transmission channels. The moment of impact with the vehicle was established by use of an electrical contact mounted at knee level of the dummy. The speed of the vehicle before impact was measured using time – velocity installations directly in km/h. The maximum of head decelerations level measured (after axes x, y, z) was covered by range 0 ± 200 G and the maximum of thorax decelerations level measured (after axes x, y, z) was covered by range 0 ± 100 G.

Each filtering channel concordant to each measurement channel was adjusted as follows: for decelerations measured in the head – the frequency domain was adjusted between 0 – 1000 Hz (according to the frequency limiting of 1650 Hz at -3 dB); for decelerations measured in the thorax the domain was 0 – 180 Hz (the corresponding frequency limit is 300 Hz at -3 dB).

The recording of decelerations (measured, amplified and filtered) was made at 0 ± 5V level for 0 ± 200g – head, respectively 0 ± 5V for 0 ± 100g – thorax, on photosensitive paper an ultraviolet ray oscillograph device, as well as magnetic-tape recorder, digitally processed by a PCM system (code processing). The measuring range adjusted for each channel of the oscillograph was 0 ± 5V = 0 ± 50mm = 0 ± 200g for head decelerations and 0 ± 5V = 0 ± 50mm = 0 ± 100g for thorax decelerations.

The measurement channels were: First contact; Head axis – X Deceleration; Head axis – Y Deceleration; Head axis – Z Deceleration; Thorax axis – X Deceleration; Thorax axis – Y Deceleration; Thorax axis – Z Deceleration.

EXPERIMENTS DEVELOPMENT

After the preparation of the necessary equipment two tests were conducted for the above-mentioned impact scenarios. The tests were conducted under conditions of straightway, dry passable covered with concrete.

During the first test, the pedestrian was set in front of the motor vehicle in a sidewise position (crossing the street), with the left leg toward the vehicle. The impact took place in the left knee area, slightly above it. Impact speed of the vehicle was 29.58 km/h and the pedestrian was hit by the vehicle's mid bumper. The brake system was engaged just 2 m before the collision took place.

During the second test, the pedestrian, placed facing the motor vehicle, was hit head-on by the mid bumper of the vehicle that was moving at a constant speed of 30.21 km/h. The pedestrian was hit in the knee area during the impact. After the tests were conducted, in order to obtain the digital format diagrams of head and thorax acceleration and speed values , the results obtained on oscillograf's paper, were scanned in „Black and White Drawing" format and saved as files in „Windows Bitmap Monocrome" format.

During the next stage, using analysis software, the files containing the acceleration diagrams were digitized. In order to accomplish this, the following steps were taken: setting the origin of the diagram and the upper limits of the X and Y axes; capturing the points off of the scanned image (The program allows the acquisitioning of as many as 1000 points off the image. The digitization can be done automatically or it can be customized by allowing the user to select the area they wish digitized); generating the database; importing the database into a specialized diagram software; drawing the diagram based on the values in the database.

By analyzing the obtained diagrams it can be stated the effective contact between the pedestrian dummy and the motor vehicle lasts for approx. 250 ms, at an impact speed of 30 km/h, after which the pedestrian falls down to the ground. The impact in the area of the pedestrian's lower limbs lasts about 90 ms after approx. 190 ms the pedestrian's head hit the windscreen. In both variants of tests the pedestrian's head was projected into the vehicle's windscreen. Also the lower limbs were broken in the contact area with the bumper. During the second test the dummy broke at the pelvis joint. This was due to the joint torque adjustment, the torque exceeding the breaking point of the joint in the welding spot. The average acceleration values recorded, from the moment of the impact in the knee area, up to the impact of the pedestrian's head with the windscreen, and during the secondary impact with the ground are as follows:

Table 1. Average acceleration values recorded at head and thorax levels of the dummy

Test no.	Primary impact		Secondary impact	
	Head [g]	Torax [g]	Head [g]	Torax [g]
1	7,525	7,338	5,78	5,137
2	10,81	10,994	10,92	8,344

RESULTS

The average impact force applied to the dummy was approximate 5300 N for the first test. During it's fall off the vehicle and to the ground, the dummy, as we can see from the acceleration diagram, did not hit the ground with it's head, but only rolled on it following the rotation motion passed on to it by the leg area impact. The accelerations that occurred during the secondary impact are smaller than the ones involving the direct collision with the motor vehicle. The greater accelerations in test number two are due to the breaking of the dummy at the pelvis joint. Following the experiments completion, the damage caused by the pedestrian to the motor vehicle, both during the first and the second tests, were significant only in the windscreen region. The hood had only slight impact traces. The bumper suffered no deformation.

Analyzing the filmed recordings and the diagrams we can state that the impact has three main stages: 1 - Contact with the motor vehicle, which lasts from the time of impact to the moment the pedestrian falls off the vehicle; 2 - Flying stage, from the moment the pedestrian falls down until the impact with the ground; 3 - The lug stage, from the moment of the impact with the ground until the pedestrian reaches the final position.

CONTACT WITH THE MOTOR VEHICLE

This stage is comprised of a series of sub-stages due to the complexity of the phenomena that occur: initial impact with the hitting of the pedestrian at the knee level; leaning the pedestrian's femur against the hood edge, simultaneously with the swinging of the upper side of the body on the vehicle's hood; rotating the pedestrian's body around his longitudinal axis; impact of the pedestrian's head with the hood; falling off the vehicle. At the initial impact the pedestrian is hit at the knee level by the vehicle's bumper. Since in the case presented the motor vehicle was braked only with the rear axle there was not notice the pitching movement while braking. Briefly after, the hood's edge comes into contact with the pedestrian's femur.

Figure 3. First test (left). Pedestrian's swinging on the hood (right)

Here we can see the „molding" phenomena of the lower limbs on the frontal area of the motor vehicle. This is due to the mobility of the joints of the lower limbs or, in the worse cases, due to the breaking of the bones. The lower area of the leg, up to the knee, tends to be pulled under the vehicle but due to the difference of weight, between this region and the rest of the body, at the end the „molding" phenomena occur. During the stage where the legs are pulled under the vehicle, ankle fractures can occur. The pedestrian's swinging on the hood is delayed as compared to the impact moment.

The pedestrian's rotation movement around its longitudinal axis arises as a consequence to the position of the dummy's leg that is first hit by the bumper. The rotation is delayed due to the mass distribution on the pedestrian's legs.

Figure 4. Second test

The falling off the vehicle, in case of low impact velocities, is generally manifested by side falling or by slipping down the hood, after the motor vehicle has stopped. In the first case the pedestrian's velocity at the moment of falling down the vehicle is equal to the vehicle velocity.

FLYING STAGE

After the pedestrian fell down the vehicle, until the secondary impact, he will trace in the air a parabolic trajectory. In the case presented this stage is almost inexistent, due to the low collision velocity. The fly stages occur only at velocities more that 40 km/h.

LUGGING STAGE

Once the pedestrian reaches the ground he will roll and will slip, the final position being completely accidental. The contact with the ground may be reached with any of the body's sides. It was noticed that after the secondary impact with the soil the pedestrian has not reached the ground with the head but only with the thorax and lower joints, rolling on the road.

DISCUSSION

From the recordings, the acceleration diagrams and the filming done, we come to the following: the maximum impact force between the vehicle's bumper and the pedestrian occurs after approx. 25ms, the result being the breaking of the dummy's leg; the value of the force at the knee level in this case was about 10000 N; the maximum acceleration was recorded at the time of the collision between the head of the dummy and the vehicle's windscreen, 190 ms after the initial impact; the value of the acceleration at the level of the head in this case exceeded 100 g; at thorax level the average acceleration value recorded over a period of 20 ms was approx. 18g and took place at the secondary impact with the ground; the projection distance of the pedestrian in the case of the first test was 7.5 m on the same direction with the vehicle motion; the damage inflicted upon the motor vehicle during the collision with the pedestrian consisted of slight impact traces in the upper part of the hood and the breaking of the windscreen; even though during the first test the pedestrian was hit with the center of the bumper, due to the swinging motion imprinted, the dummy fell off the right side of the motor vehicle, this being confirmed by the traces on the hood.

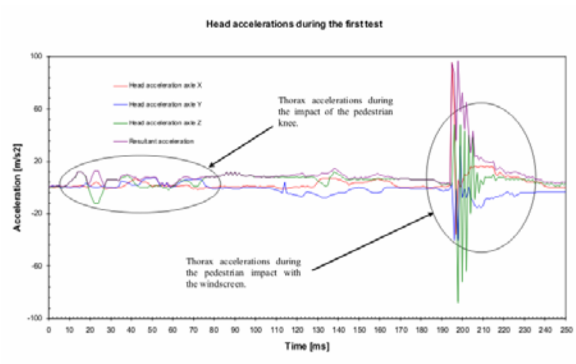

Figure 5. Head accelerations during the first test

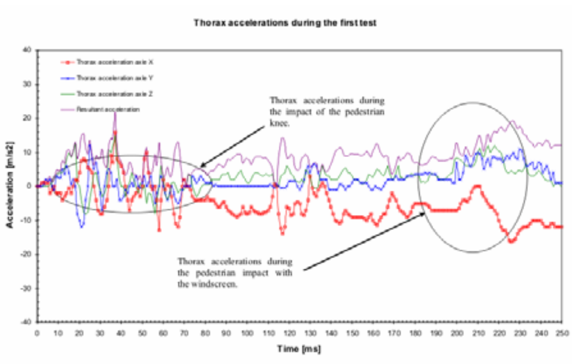

Figure 6. Thorax accelerations during the first test

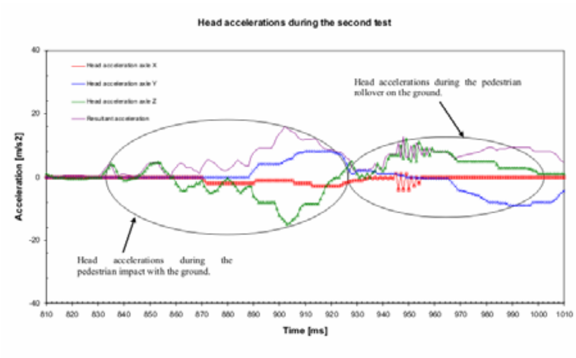

Figure 7. Head accelerations during the second test

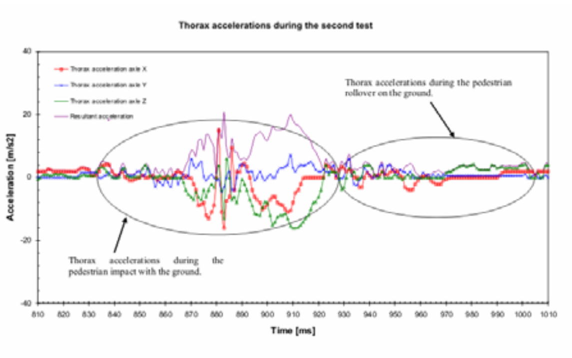

Figure 8. Thorax accelerations during the second test

CONCLUSION

The analysis of the diagrams obtained after the impacts suggests that despite the relatively low impact velocities, the accelerations that occur at the thorax and head level are important, these values being added the length of the accelerations presented. The injuries suffered by the potential victims are serious and most of the time, fatal. It is imposed that in the future the efforts of the motor vehicles manufacturers should focus on finding solutions to diminish the effects of the collision with pedestrians and, at the same time, to assure passengers' protection [1]. Another way to diminish the pedestrian-vehicle accidents number is to create a traffic infrastructure to fulfill the present requirements that are imposed not only inside but also outside urban areas (pedestrian tunnels, avoiding the junction of vehicle-designated roads with the pedestrian ones, protection panels on the margin of roads). And the last but not least, it has to be reminded the fact that the traffic education of each of the traffic participant, driver or pedestrian, plays a major role in reducing the number of traffic events.

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