

The assessment of pedestrian's head injury risk at the contact with the vehicle's hood

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Abstract. The main paper objective was to determine pedestrian's head injury risk, at the impact with the vehicle's bonnet. To achieve this objective, experimental tests on a test bench were performed. It is intended to determine the head injury risk, in different areas of the bonnet, to determine hood's "friendliness".

1. Introduction

Pedestrians represent the most significant fraction from overall road users. Simultaneously, they are considered "vulnerable road users".

Romania represents the country with the highest rate of deceased pedestrians per million inhabitants from the EU, with a 33% higher rate than the EU average [1].

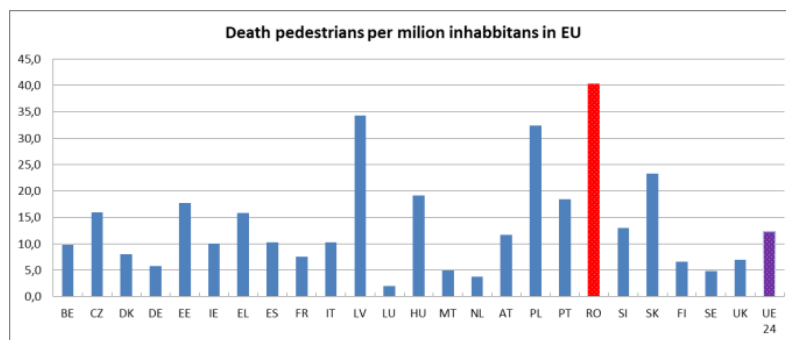


Figure 1. Pedestrian fatalities per million inhabitants in the function of EU countries [1]

Otte reported that the most common injured part is the pedestrian's head [2]. Usually, the contact between the pedestrian's head and the bonnet occurs in the final phases of the primary impact [3].

The most recent pedestrian passive safety devices are the pop-up bonnet, respectively, the pedestrian's head airbag.

The pop-up bonnet is classified according to its activation time as follows [4]:

- Passive hood – the bumper enters in contacts with the pedestrian's lower limbs
- Active hood – usually is activated before the first contact takes place

In 2012, Volvo introduced the first pedestrian airbag, consisting of the following elements: the airbag control unit, the bonnet lift cap, the bonnet hatch release mechanism, the bonnet hinges and the sensors [5].

EEVC (European Experimental Vehicles Committee) established several types of experimental tests to assess the pedestrian's safety. Thus, pedestrian safety tests are so-called component tests, avoiding full-scale tests. One of the tests consists of using a head impactor that is accelerated to hit the vehicle's bonnet, respectively windshield, in specific areas. This type of test, assess the pedestrian head injury risk, at the impact with the vehicle [6], [7].

2. Methodology

To assess the pedestrian's head injury risk, in functions of the bonnet area, three experimental tests were performed. In the first test, the area of interest was the bonnet's end part, at the connection with the windshield, for the second test, the impact took place in the center of the bonnet, while for the third test, the impact took place on the bonnet's lateral upper end.

The bonnet was mounted and fixed on the test bench, being positioned in the vertical plane. On the top side of the bench, a pendulum with the head-neck assembly was mounted. The designed test bench can be used in different scenarios: impact between the pedestrian's head with the bonnet; impact between the pedestrian's head with a pop-up bonnet; impact between the pedestrian's head with the windshield.

In figure 2 is presented the designed test bench, together with the head-neck assembly pendulum.



Figure 2. The designed test bench

In all three test scenarios, the pedestrian's head velocity was approximately 40 km/h, the same velocity used by Euro NCAP during their component testing procedures.

To determine pedestrian's head acceleration and velocity, high-speed camera recordings available on smartphones were used. The camera available on the smartphone was able to record at 480 frames per second, having a full HD recording. The recorded videos were processed in the Tracker software, from which we were able to determine the values of interest (head velocity and acceleration).

The pedestrian's head kinematics after the first test is presented in figure 3.

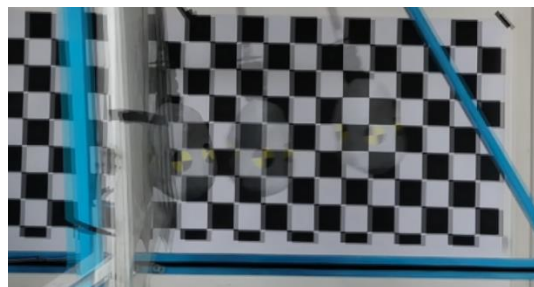


Figure 3. Pedestrian's head kinematics in the first bench-tests scenario

In the second bench-test scenario, the head impacted the center of the hood, and its kinematics is presented in figure 4.



Figure 4. Pedestrian's head kinematics in the second bench-tests scenario

In the third bench-test scenario, the head impacted the left lateral edge of the hood, and its kinematics is presented in figure 5.

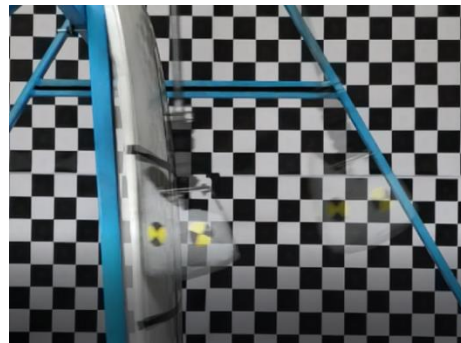


Figure 5. Pedestrian's head kinematics in the third bench-tests scenario

3. Results

The acceleration diagram resulted from the performed bench-tests, are presented in the figures below (figure 6).

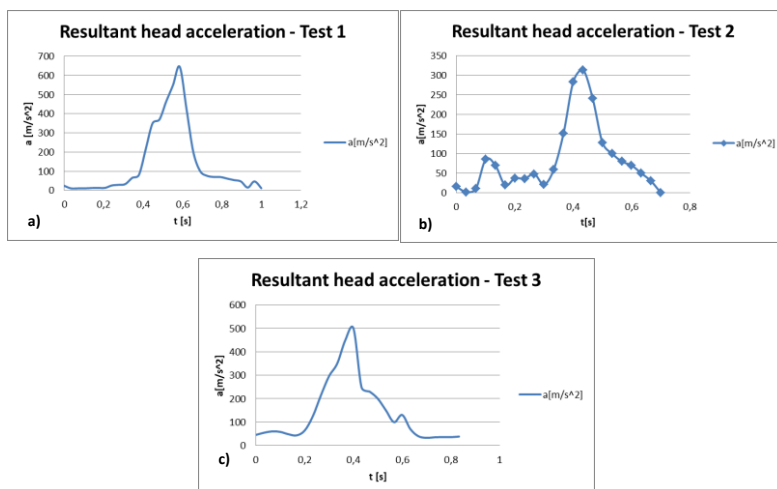


Figure 6. Resultant head acceleration for the first bench-test: a) the first test; b) second test; c) the third test

To quantify the injuries that may occur in the brain, various methods have been proposed to measure both kinematics and dynamic parameters. One of the most popular methods to determine head impact tolerance is HIC (Head Injury Criteria). The HIC value is determined by integrating the resultant acceleration, depending on the set time interval. Thus, the HIC calculation formula is [8], [9], [10], [11], [12], [13]:

$$HIC = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a \cdot dt \right]^{2.5} \cdot (t_2 - t_1) \right\}_{MAX} \quad (1)$$

Where a represents the head acceleration, measured in m/s^2 , while t_1 and t_2 , is the time interval in which is calculated the HIC value and is measured in seconds. Usually, the area of interest of HIC calculation is where the peak accelerations are.

Therefore, using Mathcad software, we were able to calculate HIC values for each bench-test:

$$HIC_{test1} = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a \cdot dt \right]^{2.5} \cdot (t_2 - t_1) \right\}_{MAX} = 500 \quad (2)$$

$$HIC_{test2} = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a \cdot dt \right]^{2.5} \cdot (t_2 - t_1) \right\}_{MAX} = 127 \quad (3)$$

$$HIC_{test3} = \left\{ \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a \cdot dt \right]^{2.5} \cdot (t_2 - t_1) \right\}_{MAX} = 281 \quad (4)$$

To summarize the obtained values, a diagram, together with the head impact locations was created and is presented in figure 7.

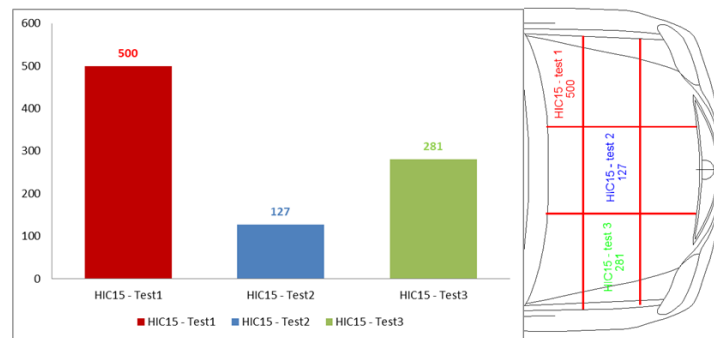


Figure 7. Obtained HIC values, in the function of head impact location

4. Conclusions

According to the obtained values, the highest chance for the pedestrian's to suffer a severe head injury is in the upper part of the bonnet (the part that connects with the lower part of the windshield), where we obtained a HIC value of 500. In the second scenario, where the impact was in the center of the

bonnet, the HIC value decreased with approximately 75%, while for the third bench-test scenario, the decreasing in comparison with the first crash test, was 56%.

Therefore, the vehicle's bonnet critical area is the upper part, where it connects with the windshield, while the safest part is in the center of the bonnet. To study the influence of the pedestrian passive safety systems (pop-up bonnet, pedestrian airbags), further tests will be performed on the designed test bench.

5. References

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