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Research on the study of frontal collision between a vehicle and a fixed rigid barrier

IRINA DUMA[1*], DRAGOȘ-DANIEL TRUȘCĂ[2], NICOLAE BURNETE[1], ADRIAN TODORUȚ[1]

[1] Department of Automotive Engineering and Transports, Faculty of Automotive Engineering, Mechatronics and Mechanics, Technical University of Cluj-Napoca, Romania
[2] Department of Automotive Engineering and Transports, Faculty of Mechanical Engineering, Transylvania University of Brașov, Romania

Abstract. The paper presents a part of the research conducted in order to establish a methodology for studying the frontal collision for a particular case. Thus, an experimental test methodology was developed considering a frontal collision between a vehicle and a fixed, rigid barrier. Two anthropometric testing devices (ATDs) were placed in the vehicle (one in the driver seat and the other one in the back seat), in order to evaluate the kinematic and dynamic parameters that characterize the occupants' behaviour in such collision. Based on the vehicle's final position after the collision, a computational simulation was performed using the PC-Crash software program. The obtained results were then compared with the data provided by the video recording of the experimental testing, in order to validate the computational simulation as a method for reconstructing road vehicle accidents.

Keywords: road vehicle, occupant, vehicle crash, frontal collision, experimental testing, computational simulation, accident reconstruction

1. Introduction

1.1. Scope and objectives of the present paper

The experimental testing of road vehicles collisions has the role of validating a series of road accident reconstruction methodologies. The present work aims to validate the computer simulation in the PC-Crash software program, version 14.0,

[*]Correspondence address: dumairina.d@gmail.com

by comparing the obtained results with those processed from experimental testing, through analysing the video recordings. Thus, the vehicle velocity during the collision phases, is compared with the velocity determined through the Tracker software program. The accuracy of the computational simulation is also evaluated from the perspective of ATDs movement during the collision.

1.2. The necessity of the proposed topic

Research on road traffic accidents arises mainly from the still high numbers of such events, as well as incidence of fatalities occurred. Although there has been a decrease in the number of road traffic accidents and the degree of mortality at the European level in 2020, these are mainly correlated with the travel restrictions imposed with the outbreak of the Coronavirus pandemic [5], after which more significant increases are observed with the year 2021 [6]. However, the current level of injuries and fatalities caused by road traffic accidents remains below the pre-pandemic level [6], but it is far from reaching the objectives of the European Commission's *Vision Zero*, which aims to completely eliminate serious injuries and deaths from these causes [7].

Frontal impact with a fixed rigid obstacle presents a higher risk of serious injury and even death than other types of collisions, because the impact energy is absorbed exclusively by the vehicle's frontal structure, and the accelerations and decelerations that occur at the level of the human body can lead to internal injuries which are incompatible with life. For example, in [14] it is highlighted the risk of death due to neck fractures that can occur even at low travel speeds, especially when the vehicle occupant is not wearing seat belt. Thus, the proposed topic is of interest from the perspective of evaluating the possibilities of optimizing the frontal structure of road vehicles, as well as the passive safety systems intended to restrain occupants, so that the effects of such collisions are minimized. For this, it is necessary to know the circumstances in which traffic accidents occurred in order to correlate the data taken from real cases with the proposals for optimizing the vehicle's systems. In this sense, the present paper aims to validate a computer simulation methodology using the PC-Crash software program based on an experimental test, in order to improve the processing of data from real traffic accident situations.

1.3. State of the art

With regard to the standardized experimental tests for the safety assessment of new vehicles, it is noted that the frontal impact with a fixed rigid barrier with full overlap is addressed by EuroNCAP (for Europe), JNCAP (Japan), KNCAP (Korea) and ANCAP (Australia and New Zealand). In the case of EuroNCAP (figure 1.a), the full width rigid barrier frontal impact is performed at a speed of 50 km/h, aiming to evaluate seat belt efficiency for occupants restrain, with the purpose of reducing the decelerations that occur due to the vehicle's structural rigidity [1]. For the Japanese market, the frontal impact with fixed rigid barrier test (figure 1.b) is carried out at a vehicle speed of 55 km/h [8], while in Korea (figure 1.c) the vehicle travels at speed of 56 km/h [9]. On the other hand, the Australian and New Zealand authority responsible for assessing safety levels of new vehicles, approaches this kind of collision with a vehicle travelling speed of 50 km/h [3]. However, it is noticed that for the United States region, the authority in charge with testing new cars does not take into consideration the full width frontal collision with a fixed, rigid barrier [2].

a)

b)

c)

Fig. 1. Standardized experimental tests of the full width frontal collision between a vehicle and a fixed rigid barrier:
a - frontal impact with fixed rigid barrier conducted by Euro NCAP [1]; b - frontal impact with fixed rigid barrier conducted by JNCAP [8]; c - frontal impact with fixed rigid barrier conducted by KNCAP [9].

In the specialized literature, experimental testing is a mean of validating some methodologies for analysing the vehicle's behaviour during a collision. For example, in [13] a computer simulation method using finite element analysis of the behaviour of the frontal part of the vehicle is validated, by experimentally testing a frontal collision at low travel speeds. In [12], the computer simulation using the

PC-Crash software program is addressed, for determining the equivalent impact velocity in the case of a frontal collision between two vehicles.

Also, research in the field increasingly approach the analysis of video recordings of traffic accidents in order to reconstruct such events, through the possibility of correlating these images with computer simulations, in order to determine the dynamic and kinematic parameters – velocities and travel distances –, that characterize these collisions [4]. The most often used data is acquired through video recordings from fixed traffic cameras, generally placed in intersections [11], but video cameras installed inside vehicles have also proved to provide relevant data regarding the circumstances in which road accidents were produced [10], by tracking a fixed point throughout the recording run.

2. Experimental testing of the frontal collision between a vehicle and fixed rigid barrier

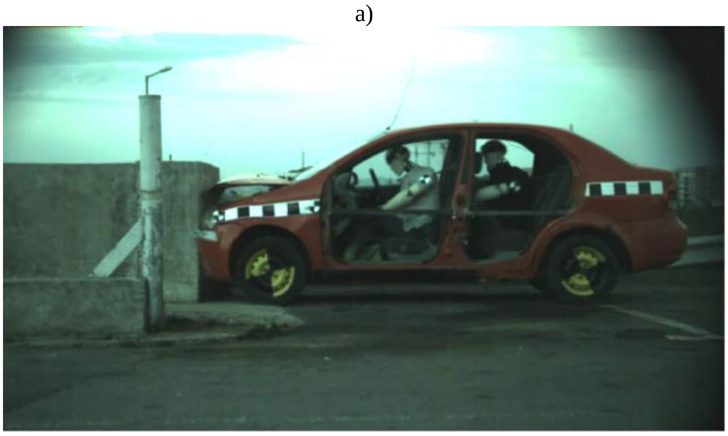
For the present study, the experimental test of the frontal collision between the road vehicle and the fixed rigid barrier was carried out within the Research and Development Institute of the "Transilvania" University of Brașov, Romania. The main constructive-functional parameters of the used vehicle are presented in table 1. Inside the vehicle, two 50% male anthropometric testing devices (ATDs) were placed, one in the driver's seat and the other one in the back seat. Each of the two ATDs has a mass of 87 kg.

Table 1. Main parameters of the tested vehicle.

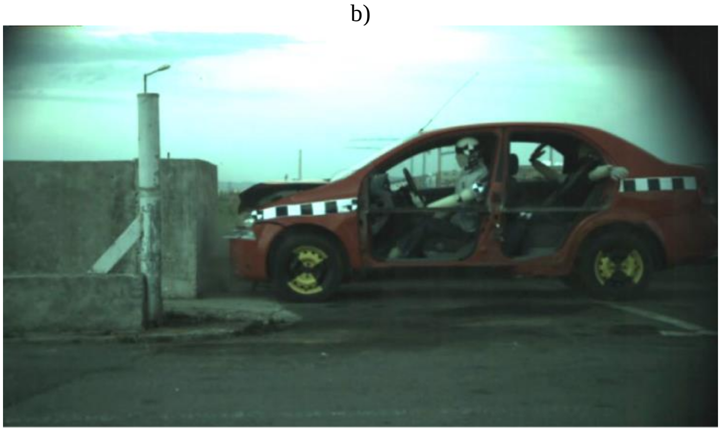
Engine capacity	1399 cm^3
Vehicle mass	1025 kg
Total mass (with ATDs included)	1199 kg
Total length	4240 mm
Total width	1670 mm
Total height	1495 mm
Wheelbase	2480 mm
Trackwidth (front, rear)	1450 mm
Ground clearence	210 mm
Front console	800 mm
Rear console	960 mm

The experimental test consisted of towing the tested vehicle by another vehicle, by using a towing hook, while the desired direction was maintained by means of a guide rail fixed on the road surface, so that the contact with the fixed rigid barrier takes place on the entire surface of the vehicle's frontal part, thus obtaining full overlap. Thus, the evaluation of the velocities and accelerations that occur at vehicle level in all three phases of the collision was pursued: the pre-collision phase, the actual collision, and the post-collision phase (figure 2). This data was obtained by processing the video recordings made by a high-speed camera. The parameters resulting from the video processing of the experimental test served as reference data for verifying the validity of the proposed computational simulation methodology

a)



b)



c)

Fig. 2. The collision phases of the frontal impact between the tested vehicle and the fixed rigid barrier:
a - pre-collision phase; b - the actual collision; c - the post-collision phase.

A GPS Garmin device was installed in the tractor vehicle (figure 3), with the purpose of recording the geospatial position of the vehicle used to tow the tested vehicle, in order to verify the data further obtained in terms of velocity regime.

Fig. 3. The GPS Garmin device used to record the geospatial position of the tractor vehicle.

The final position of the vehicle after the impact, as a starting point for carrying out the computational simulation, is shown in figure 4, from which it is observed that the impact force occurred during the collision leads to a recoil movement of the vehicle, thus determining it to travel in the opposite direction during the post-collision phase, at a certain distance from the fixed rigid barrier.

a) b)

c) d)

Fig. 4. Final position of the tested vehicle after the impact:
a - left view; b - top view; c - front view; d - right view.

3. Analysis of the experimental test video recording

The video recording of the impact, made with a Hi-Spec 5 high-speed video camera, was processed using the Tracker program, starting from the calibration of dimensions from the images, relative to a Cartesian system having the origin positioned in a point that remains fixed during the entire duration of the recording. Then, centres of mass positioned on the grid were chosen for each studied point, namely the side of the vehicle, and the head and shoulder of each ATD, respectively (figure 5). Finally, it was aimed to extract data regarding the evolution of the travel speeds of these centres of mass during the duration of the video recording.

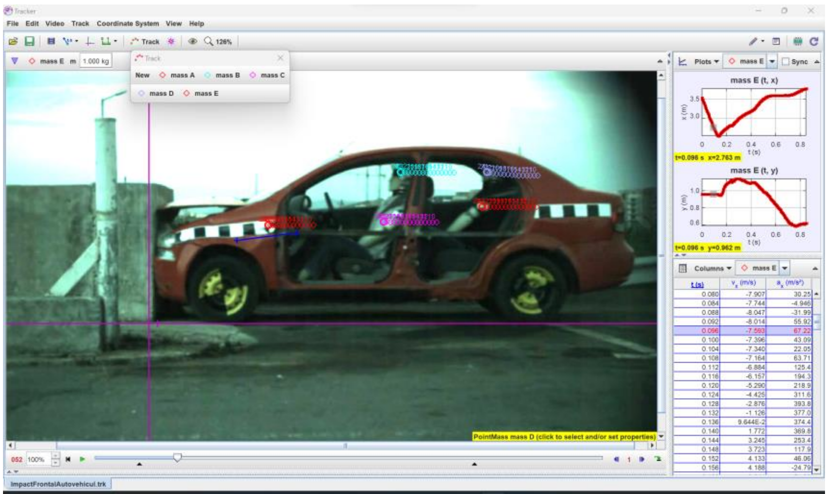


Fig. 5. Analysis of vehicle and ATDs kinematics through video recording processing, by using the Tracker program.

4. Computational simulation of the frontal collision between the vehicle and the fixed rigid barrier

The computational simulation of the frontal collision between the vehicle and the fixed rigid barrier was carried out starting from the final position of the vehicle (see figure 4), which was introduced into the PC-Crash software program, version 14.0, as depicted in figure 6.

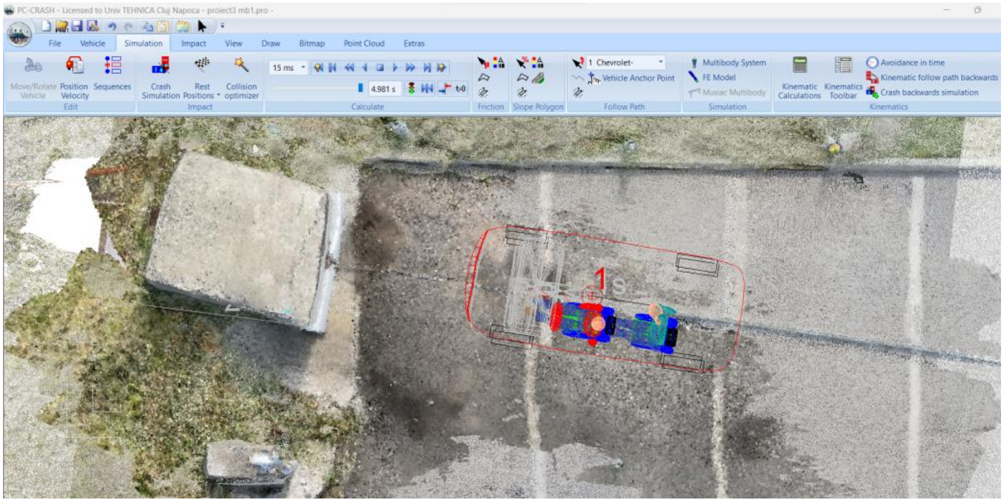


Fig. 6. Realization of the computational simulation starting from the final position of the vehicle (top view).

In order to evaluate the kinematics of the occupants, multibody models were introduced in the simulation, thus resulting their movement in different moments of the collision (figure 7).

a)

b)

c)

Fig. 7. Occupants' movement during the collision phases, according to the computational simulation a - pre-collision phase; b - the actual collision; c - the post-collision phase.

5. Obtained results. Conclusions

From the processing of the data obtained through the Tracker program for the analysis of the video recording, it is found that the maximum travel velocity of the vehicle in the analysed timeframe was 29.73 km/h, and at the moment of the actual collision, in time interval 0.056÷0.064 s, the impact velocity was in the range of 29.27÷26.73 km/h (figure 8). The negative values for the vehicle velocity that appear starting from time 0.12 s refer to the beginning of the post-collision phase, when the vehicle moves in the opposite direction due to the recoil phenomenon.

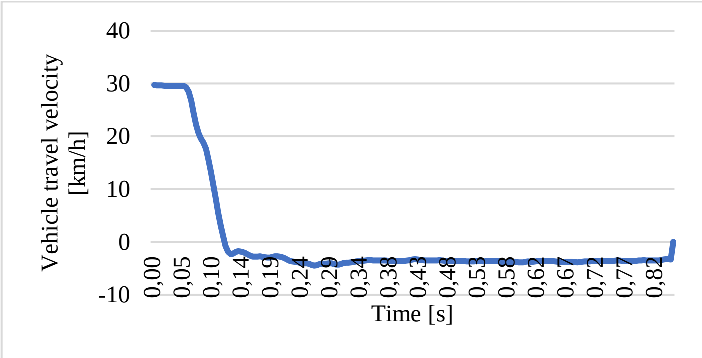


Fig. 8. The evolution of the vehicle travel velocity, during the experimental testing, determined through the analysis of the video recordings.

Regarding the kinematics of the ATDs having the role of the driver, respectively of the occupant behind him, it is noted that the relative displacement with respect to the vehicle begins at the moment of the actual collision and until the complete stop of the vehicle in the post-collision phase. Thus, longitudinal velocities at the head and shoulder (thorax) of the ATDs occur.

For the driver's head, the maximum recorded speed at the moment of the collision is 29.27 km/h, while for the thorax it is 30.09 km/h. In the post-collision phase, during the recoil phenomenon, the maximum speed is 14.96 km/h for the driver's head, respectively 7.66 km/h for the driver's thorax (figure 9).
In the case of the back seat occupant, there is an increase in the maximum speed of the head, of 28.89 km/h in the actual collision phase, and of 16.80 km/h in the post-collision phase. For the occupant's thorax, the speed during the collision is 29.13 km/h, and 14.61 km/h in the post-collision phase (figure 10).

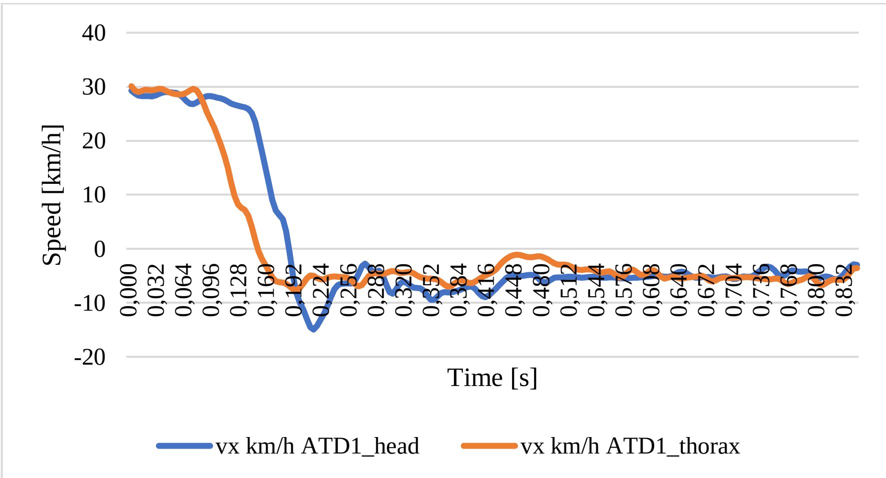


Fig. 9. Evolution of driver's head and thorax speed during the experimental test, determined through the analysis of the video recordings.

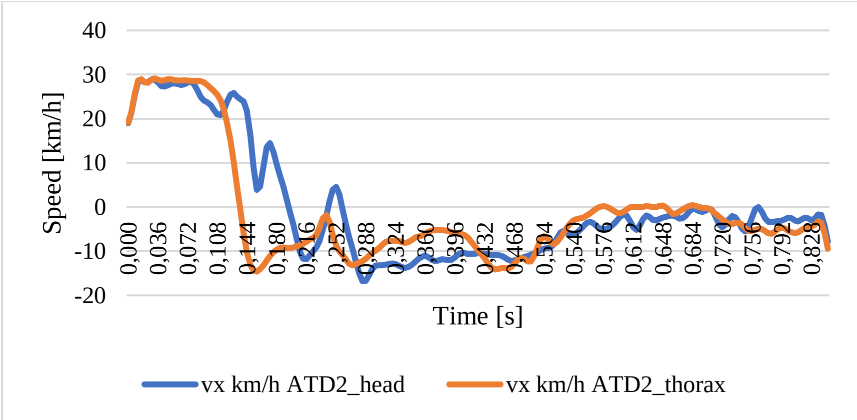


Fig. 10. Evolution of the back seat occupant's head and thorax speed during the experimental test, determined through the analysis of the video recordings.

According to the computational simulation, the vehicle velocity at the moment of collision was 29.70 km/h (figure 11), similar to that obtained from the video recording processing, which was in the range of 29.27÷26.73 km/h. At the same time, the movement of the occupants is reproduced in the computational simulation (see figure 7) in a similar way to the movement of the anthropometric test devices during the experimental test (see figure 2). Thus, this represents a valid means of determining the impact velocity of a road vehicle, under the conditions in which it is possible to analyse the accident site and the final position of the vehicle, respectively to precisely measure the plastic deformation of the vehicle's body. However, there are several limitations regarding the determination of the accelerations that occur at the vehicle, as well as occupants level.

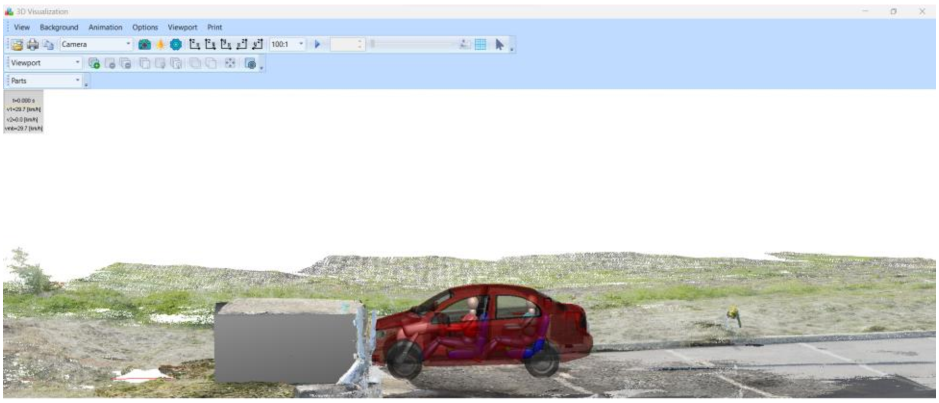


Fig. 11. Running of the computational simulation in order to determine the vehicle's impact velocity.

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