ANALYSIS OF PEDESTRIAN PASSIVE SAFETY WITH THE USE OF NUMERICAL SIMULATION

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Abstract

Despite of the awareness of the pedestrians' poor passive safety, the research has aimed mainly at the reduction of car occupants' accidents and fatalities. The paper proves that the decline in severe injuries of a pedestrian is feasible, as far as the car front constructi on is pedestrian oriented. Additionally, the technical units such as frontal protection system, fitted on the car, should at least comply with the current regulations. The expansion of the Finite Element Method (FEM) enabled the authors to imp lement it to the stated problem. It encompassed the pedestrian safety in terms of a collision with the front of a motor vehicle with the frontal protection system mounted. The research procedure mirrored the car vs. pedestrian collision described in Regulation (EC) 78/2009 and (EC) 631/2009 which lays down the rules concerning the boundary conditions. The carried out virtual tests – utilizing the numerical, certified impactors - were further contrasted with the results of the physical experiment. As the consequence of the research, the authors design the frontal protection system which agrees with the current requirements. Furthermore, they managed to create their own methodology for pedestrian passive safety enhancements.

Keywords: *pedestrian passive safety, finite element method, Regulation (EC) 78/2009, virtual simulation*

1. Introduction

The automotive industry, in spite of the recent market oscillation, is still dynamic and swiftly growing branch of the world production. The continuous motor vehicle demand bases on their state-of-the-art functionality, comfort as well as the heighten design or prestige. Nowadays, among stated features, safety aspects – both passive and active – play a great role in traffic. It is because a passenger car is usually bought for its driver. A customer invests considerable amount of money in systems, which might reduce the injury risk or even safe lives of whose, who travel in the purchased car. After this statement, one can come to the conclusion, why the vehicle elements, which potentially could have slower the pedestrians' fatality growth rate, had not been implemented in cars for years. The customer of a vehicle is the occupant oneself so this interest is evidently dominating. As long as a car owner is not conscious about the potential danger to the vulnerable road users, one will not invest additional money for the pedestrian protection system.

Hence, it must be stressed, that on the European Union roads around 12-35% of serious injured or killed people account for pedestrians [1, 6]. Whereas in the developing countries, where the road infrastructure is in relatively poor condition, this percentage is estimated to 75% [7]. Such a high fatality ratio is a result of, at least, two crucial issues. Firstly, pedestrians are often disregarded as rightful road users. Pavements, crossings, traffic lights are usually adjusted to drivers and theirs machines, yet not for those, who are not secured with the seat belts, airbags or sit behind the crumple zone. The week premeditated traffic organization or mistakes made during the planning stage bring the fatal consequences. However, this paper moves another essential aspect. That is the vehicle frontal construction in regard to the pedestrian safety. As it was mentioned, at the early stage of pedestrian protection improvements, the action focused mainly on the attempt to separate pedestrians from vehicle traffic. The integration in the front car design and its construction was rare. It seemed that in the event of a collision with a relatively heavy and rigid car, travelling at 40 km/h, a vulnerable road user is subjected to severe, if not fatal, injuries. What is more, the pedestrian-involving accidents were considered tough to reconstruct due to many influencing factors. All of these aspects delayed the implementation of norms and regulations described below.

2. Pedestrian safety assessment – frontal protection systems

The development of existing test methods bases on in-depth analysis of real life car-to-pedestrian accidents. The first group, which was in involve in this analysis for the legislation sake, was European Experimental Vehicle Committee (EEVC). In 1988 Working Group 10 – further renamed into Working Group 17 – was formed as a unit of EEVC. The main goal of the Group was to expand test methods and regulations which outlined the recommendations for the vehicle front structure design. In other words – the core of the mandate of the Group was to "determine test methods and acceptance levels for assessing the protection afforded to pedestrians by the fronts of cars in an accident (…)" [2]. In February 2009 European Commission, basing on the experience gained by EEVC, issued a Regulation (EC) 78/2009 – amending the Directive 2005/66/EC – concerning the homologation of motor vehicles. What is essential, for the authors of this paper, is the fact that the Regulation refers also to the frontal protection systems in terms of pedestrian safety.

The frontal protection system, fitted to the front of a vehicle as depicted in Fig. 1, was initially designed to provide additional frontal protection in case of a collision against an animal.

Fig. 1. Frontal protection system fitted to the front of the SUV

However, the frontal protection systems, as well known "bull bars" – since cattle used to be a primary danger in rural areas – have got increasingly popular recently. What is perilous, not only in country regions, where they may perform in agreement with the essential design, but also in urban traffic. Since they are usually made of rigid steel or aluminium tubing, they are regarded as harmful to pedestrian [5]. To make matters worse, the bull bars are usually fitted to SUVs (Sport Utility

Vehicles) which percentage in agglomerations is rapidly growing. The SUV type of a car is considered as hazardous to a pedestrian because of its high bonnet leading edge. A frontal protection system, constructed without taking into account pedestrians, may considerably increase this hazard.

The purpose of the research, described in this paper, was to design a frontal protection system which would meet the current requirements connected with pedestrian passive safety. Ultimately, the research is to be regarded as a fundamental for the homologation of the unit on the European Union market.

3. The design of the frontal protection system – methodology

The great development of computation power and expansion of Finite Element Method (FEM) enable to widen the possibilities and application field of numerical simulations [8]. The pedestrian safety in terms of a collision with the front of a motor vehicle can be a good example of employing FEM. In addition, FEM is utilized in order to reduce the costs and time needed to carry out a pedestrian-to-car front test.

To launch a virtual simulation, the CAD (Computer-Aided Design) representation of the vehicle needed to be developed. It is worth noticing that the model was obtained by the use of another advanced technique RE (Reverse Engineering). The RE made possible to scan the front of the car and transfer the results as a point cloud. Afterwards, the point cloud was converted into a usable 3D CAD model. From this stage, finite elements could be generated. The attention was particular turned towards the excellence of the model and boundary conditions since the quality of the input determines the level of the output. Therefore, each individual component and element had to bear particular physical and material characteristic (i.e. thickness, stiffness, strain rate or failure criteria). According to [3] the accuracy of simulation may suffer from the actual precision of the material. In this connection, appropriate dynamic yield stress for the correct strain rate had to be correctly inputted. Otherwise the obtained results would have borne significant errors.

Once the discrete model of the SUV car and frontal protection system were done, the authors had to verify the parameters encompassed in the Regulation (EC) 78/2009. The car-to-pedestrian virtual simulation can be credible, provided that the certified numerical impactors are applied. Therefore, the impactors used in this stance – since there are certified – are bases for legal processes including homologation or Euro NCAP tests. Fig. 2 depicts the visualization of a collision between SUV, with a bull bar fitted, and a pedestrian. The numerical impactors, which imitate the performance of crucial human limbs, can be spotted in the figure. The simulation, according to the Regulation (EC) 78/2009, covers:

1. Legform test to prevent leg fractures and knee joint injuries,
2. Upper legform to prevent femur and hip fractures and injuries,
3. Headform test to prevent life-threatening head injuries.

Basing on biomechanical criteria and injury records, the above tests shall meet some limits to ensure that the risk of the serve injuries during a real on-road accident is minimized. The fundamental assessment criteria, which are applied for pedestrian impact test, are abridged in the following Tab. 1. The impactors are fired into a stationary car at speeds up to 40 km/h.

Tab. 1. The limit values for the pedestrian impact test [5]

Body from Impactor	Injury criterion	Limit
Lower legform	Knee bending angle	21.0°
	Knee shear displacement	6.0 mm
	Upper tibia acceleration	200 g
Upper legform	Sum of impact forces	5.0 kN
	Bending moment	300 Nm
Child headform	Head Injury Criterion	1000
Adult headform	Head Injury Criterion	1000

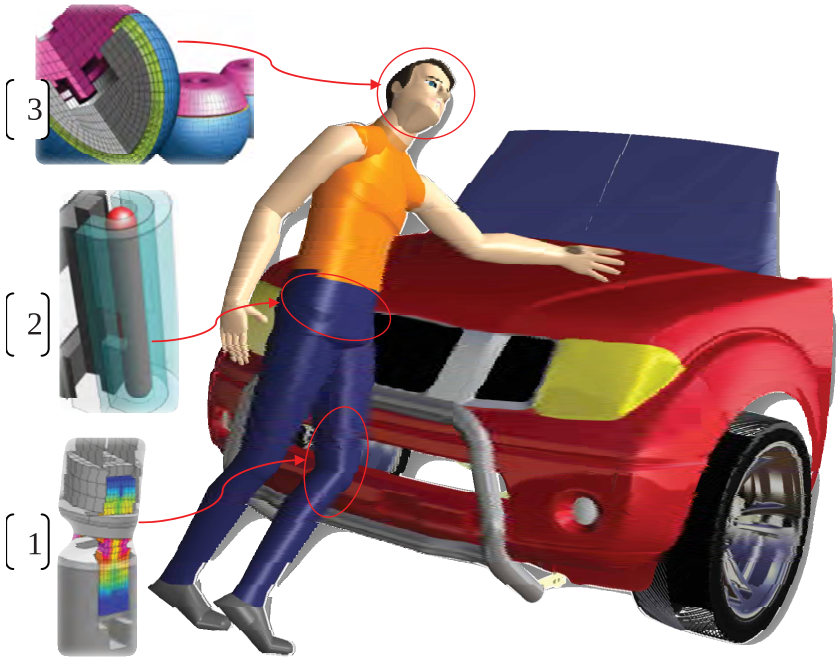

Fig. 2.The SUV-to-pedestrian collision utilizing numerical impactors

The values listed in Tab. 1 were treated as a guideline for the frontal protection system optimization. In other words, none of these limits could be exceeded to ensure that the pedestrian protection requirements are met.

Figure 3 presents the masterminded overall methodology which concerns the pedestrian safety in case of a collision with a car.

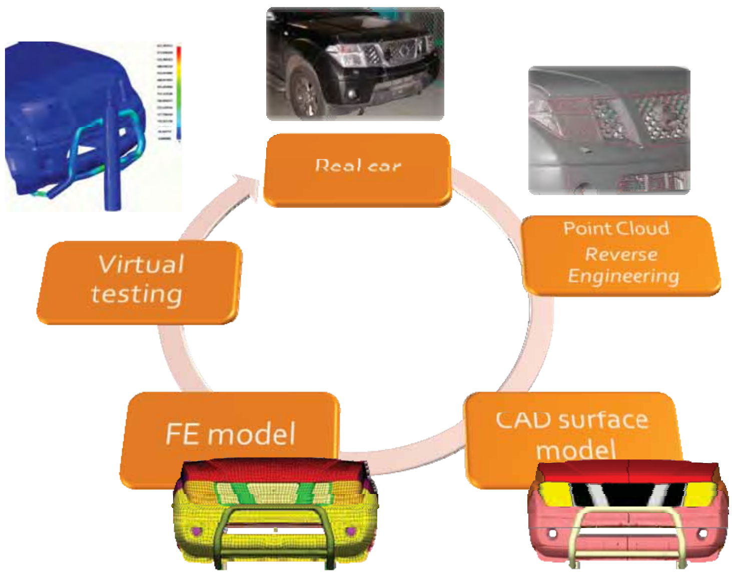

Fig. 3. The research methodology

4. Results

The complete model was virtually simulated under various dynamic conditions specified in the legislation [4,5]. Explicit LS-DYNA code was used to verify the frontal protection system performance against the limits. Fig. 4 depicts the virtual model of the SUV front with the bull bar mounted in collision with lower (a)) and upper (b)) legform numerical impactor. Although the figure depicts two different designs of the bull bars, it has to be noticed that each bull bar unite had to fully validated. Obviously, in case of failing the first test with the lower legform, the frontal protection system had to be either redesign, it terms of the bars themselves or its fitting.

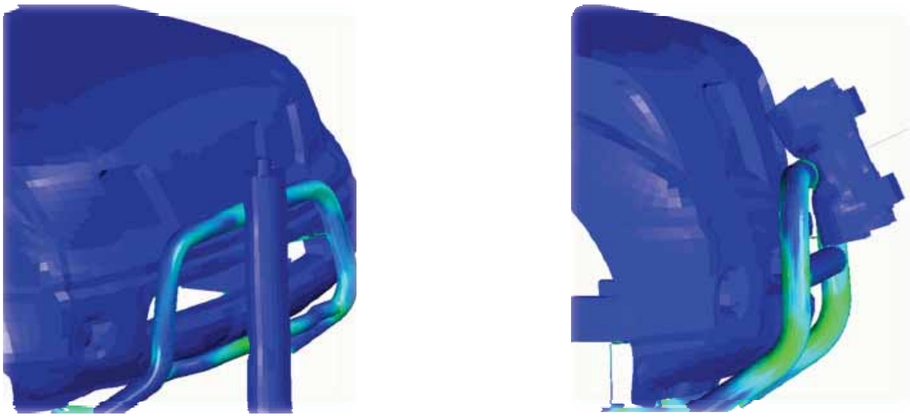

Fig. 4. The numerical simulation testi ng frontal protection syste m performance: a) lower legfor m test; b) upper legform test

In the Fig. 4 a) there is a bull bar shown which did not pass the pedestrian safety test. Whereas the knee bending angle and the tibia shear force were below the limits, the upper tibia acceleration excided the 200 g limit. However, the values obtained during the numerical simulation agreed with those obtained in a real experiment (physical test). Fig. 5 presents the acceleration curve from the numerical simulation contrasted with the one from the physical experiment. The curves have comparable run and, what is important, similar peak value. Therefore, it is confirmed that the precision level of the model is acceptable for further investigation.

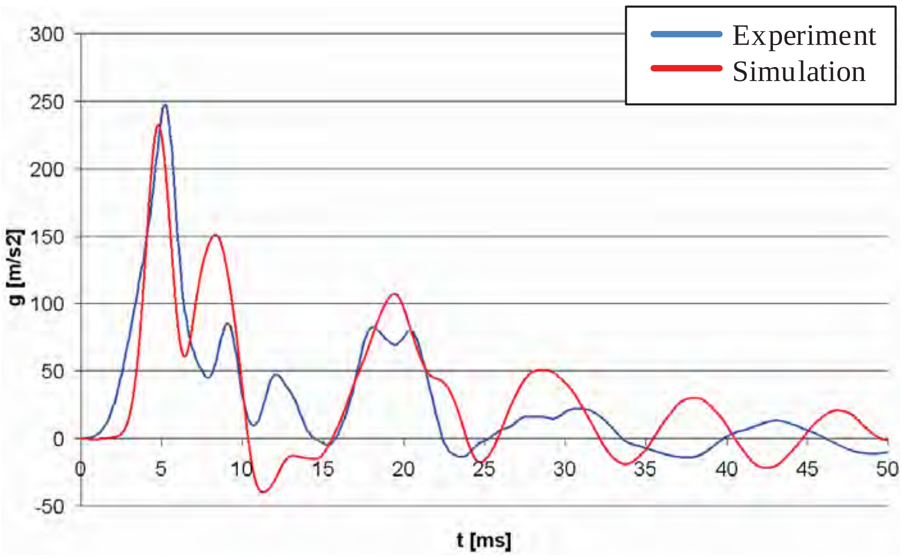

Fig. 5. The numerical simulation testi ng frontal protection syste m performance: a) lower legfor m test; b) upper legform test

On the other hand, Fig. 4 b) depicts the redesigned unit which comply with all the requirements included in the Regulation (EC) 78/2009. The maximum values of all parameters for each impactor are within the limits, thus the final concept of the bull bar shall not be hazardous for pedestrians. Hence, the design of the presented bull bar design is a base for legal process such as EU homologation.

5. Conclusion

Pedestrian safety is consensus between many crucial factors such as car design and its frontal aggressiveness, roads and pavements layout and speed limits. Frontal protection systems (also known as bull bars) are popular among the SUVs. Since the general number of these vehicles has recently increased on urban roads, it became compulsory to test the frontal protection system against the current regulations. Basing on the legislation and studies, the lateral impact between the vehicle and a pedestrian was considered and presented. Non-destructive nature of simulation enabled the authors to analyze many potential concepts and decreases the costs of the overall design process. Indeed, the numerical impactors were used for commercial purpose to optimize the frontal protection system. The obtained concept complies with the current Regulation (EC) 78/2009. Additionally, the experiment results show good conformity with the outcomes from numerical simulations. Finally, during the research on the pedestrian passive safety, the authors' methodology was compiled.

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