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# VIRTUAL TESTING IN TERMS OF PEDESTRIAN SAFETY IMPROVEMENTS

## Abstract

Pedestrian fatalities in traffic accidents continue to be a significant social burden and pose a costly hospitalization problem. Statistical research conducted in European countries onfirms that pedestrians  account for 12-35% of severelyinjured or illed victims of road traffic accidents. The paper outlines the European test procedure and a pedestrian safety guideline drawn up by the EEVC (European Enhanced Vehicle-Safety Committee). In addition, the emphasis is put on the Virtual Testing regarding the current regulations. The great development of computation power and expansion of Finite Element Method enables to widen the possibilities and application fields including pedestrian safety in terms of a collision with the front of a motor vehicle.

## Introduction

The interaction between pedestrian and vehicle traffic is considered as the main accident cause. However, even in the most developed countries, where the road systems are designed with regard to pedestrian protection, such an interaction is nowadays unavoidable. Especially in agglomerations which accounts for 70% of total pedestrian fatalities. Annually more than 1.17 million people die in road crashes around the world and 40,000 in 25 countries of European Union [1], while 65% percent of global deaths involve pedestrians. The collision takes place in a situation when an unprotected road user shares a part of road with a vehicle. According to statistics [2], in a vehicle-pedestrian impact, the majority of pedestrian fatalities occur on pedestrian crossings. Their localization is still a compromise between safety regulations, accessibility and traffic capacity. On the other hand, at the early stage of pedestrian protection improvements, the action was focus mainly on the attempt to separate pedestrians from vehicle traffic without any integration in the front car design and its construction. 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. Fig. 1 depicts the types of the vehicles most frequently involved in pedestrian accidents and simultaneously shows significant number of passenger cars in relation to pedestrian accidents occurrence.

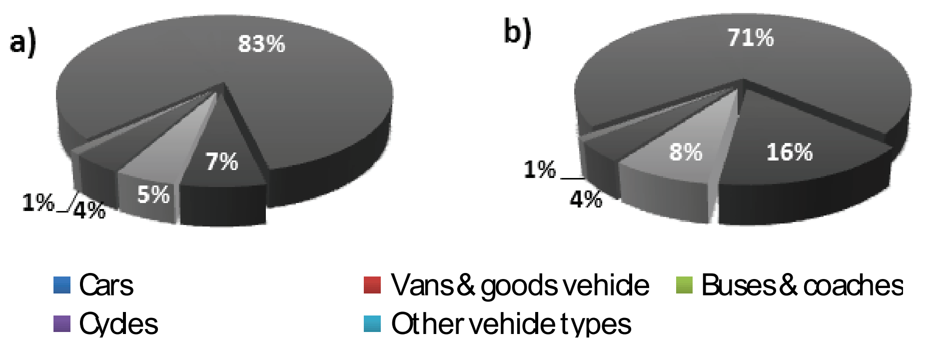


Fig. 1 Proportions of vehicles involved in pedestrian accidents: a) fatal; b) serve [3]

However, the promising development of car crashworthiness and the improvements regarding the crumple zone in the late 1950s were an inducement for engineers. It was noticed that the impact absorbing zones in the front of a vehicle may significantly contribute in reducing the number of injuries to pedestrians. Moreover, the design of the modern cars has been changed in the last years. The bonnet leading edge of new cars tends to be smooth shaped, comparing to the former rectangular shaped fronts with a sharp corner leading edge. It can be a good example of pedestrian orientated design. What is more, the assessment procedures - both physical and virtual - play a key role in improvements as regards the passive safety performance of car fronts.

**Pedestrian safety tests**

According to scientists [1] it is not currently possible to carry out a test which would reflect the variety of accidents with pedestrians. Nevertheless, the development of presented test methods bases on in-depth analysis of real life car-to-pedestrian accidents. One of the first groups which examined the fronts of the vehicles in terms of pedestrian protection was Working Group (WG) 7 of the European Experimental Vehicle Committee (EEVC). Afterwards, WG 10 was formed in 1988 and it was represented by the research institutions as well as automobile industry.

Test methods and regulations are mainly proposed by EEVC which also outlines the recommendations for the front structure design. The core of the mandate of Working Group 10 was to "*determine test methods and acceptance levels for assessing the protection afforded to pedestrians by the fronts of cars in an accident (...)"* [4].

In 1997 the former WG 10 was transformed into a new EEVC Working Group 17 which continues the works on the enhancement of pedestrian protection. The tests and test devices have been refined since then and the latest report was released in 1998 with 2002 updates. In February 2009 a new European Commission regulation (EC) No. 78/2009 on pedestrian protection was published. It repeals and replaces the current EC directives concerning pedestrian protection (2003/102/EEC) and also frontal protection systems (2005/66/EC). It applies to passenger cars, multipurpose passenger vehicles, and goods vehicles with a gross vehicle weight less than 2,500 kg. However, after a certain transitional period the regulation will be applied to vehicles exceeding this mass limit due to increasing number of heavy vehicles being used on roads.

It is worth to notice that the legislation developed by EEVC is a base and guideline for European New Car Assessment Programme (Euro NCAP). The conducted tests assess the pedestrians protection level according to the limits proposed in the EEVC test procedures- as described in [4]. Euro

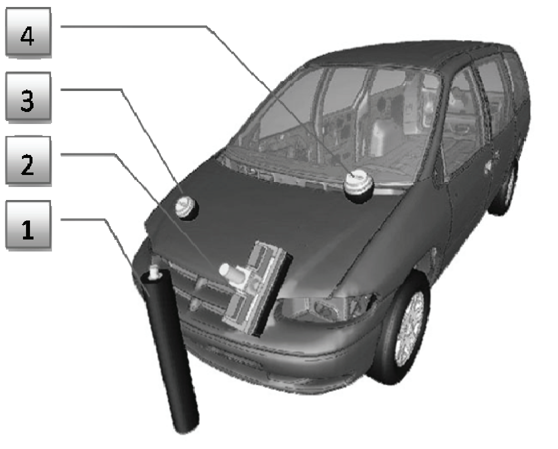

Fig. 2 The pedestrian tests according to EEVC by means of numerical impactors [6]

NCAP is often entitled by the European Commission as a motivator for passive safety (in-crash) and recently also active safety (collision prevention) [5]. The test overview is depicted in Fig.2.

The tests comprise:

1. Legform to bumper test to prevent leg fractures and knee joint injuries;
2. Upper legform to bonnet leading edge test to prevent femur and hip fractures and injuries;
3. Child headform to bonnet top test to prevent life-threatening head injuries;
4. Adult headform to bonnet top 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 summarized in following table 1. The impactors are fired into a stationary car at speeds up to 40 km/h. While the limits are to be more stringent starting from 2013, the automotive industry has indicated many areas where there is concern with the technical feasibility of these requirements [7].

Table 1.

The value of limits for the pedestrian impact test [8]

| 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 |

There are some ways to meet the EEVC requirements such as the energy absorbing components, the use of crush depth under the bonnet or a pop-up bonnet to cushion a head impact and also implementation of external airbags. Further in this paper, an example of a SUV (Sport Utility Vehicle) is put forward to present the utilization of a frontal pedestrian protection system to comply with the current regulation. As it has been mentioned, the state of art virtual tests employing FEM enabled to redesign the car front. Moreover, there is considerable time and cost savings comparing to physical tests, whereas more data from the impact can be probed.

**Computer simulations vs. pedestrian passive safety**

Computer simulations have been developing consequently with the rapid growth of advanced computers and were originally introduced for the nuclear power industry. Currently, their contribution in the car designing process is crucial. Additionally, when the Finite Element Method was implemented and started to be used by appropriate software the complex calculations, including safety issues, became achievable. What is more, Euro NCAP pedestrian protection rating released in 1997 was also a trigger for a fruitful start of virtual tests. Nowadays, numerical simulations constitute the basis for the Computer-Aided Engineering (CAE). The great development of computation power and expansion of Finite Element Method enables to widen the possibilities and application field also including pedestrian safety in terms of a collision with the front of a motor vehicle. The FEM is also utilized in order to reduce the costs and time needed to carry out a pedestrian-to-car front test using certified impactors.

The authors of this paper used FE models of vehicles for homologation, development support as well as additional component testing. However, to launch a virtual simulation the CAD (Computer-Aided Design) representation of the vehicle was needed to be developed. Although it is not the point of the paper, it is worth noticing 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 (further shown in Fig.4). From this stage, finite elements could be generated. The attention was particular turned towards the excellence of the model and applied boundary conditions since the quality of the input determines the level of the output. Therefore, each individual component and element must bear particular physical and material characteristic (i.e. thickness, rigidity, strain rate or failure criteria). According to [1] the accuracy of simulation may suffer from the actual precision of the material which is submitted to complex loading conditions. In this connection, appropriate dynamic yield stress for the correct strain rate must be correctly inputted. Otherwise the obtained results may bear significant errors.

**Virtual impactors**

The simulation is crucial to identify the human body dynamic during a collision with a car front. Some finite element impactors- as these certified ARUP models developed to use with LS-DYNA analysis code- were created in purpose to accurately define the parameters included by EEVC WG 17 and (EC) No. 78/2009. The impactors have been already presented in this paper (compare Fig.2), yet there are an important factor for the accurate simulation that more attention is here devoted. In fact, the data during a car-to-pedestrian impact are probed within the impactors (not the vehicle) since they imitate the performing of a human body in a real on-road accident. Therefore, only the use of certificated impactors (such as these presented in this stance) is considered as a base for legal processes- including car homologation or Euro NCAP tests. Fig. 3 depicts the example of a car bumper hitting the lower leg impactor. As it was indicated in table 1 the acceleration of upper tibia should be less than 200 g, whereas bending rotation and shear displacement at the virtual knee must be below 15° and 6.0 mm accordingly.

If the limits are exceeded the front design or construction must be changed- otherwise the car will not be entitled for EC type-approval on grounds related to pedestrian protection. It becomes clear why the virtual tests play such a significant role in safety aspects. Nondestructive nature of simulation enables the engineers to analyze many potential concepts and decreases the costs of the overall design process. Indeed, the numerical impactors were used by the authors of this paper for commercial purpose to optimize a frontal protection system.

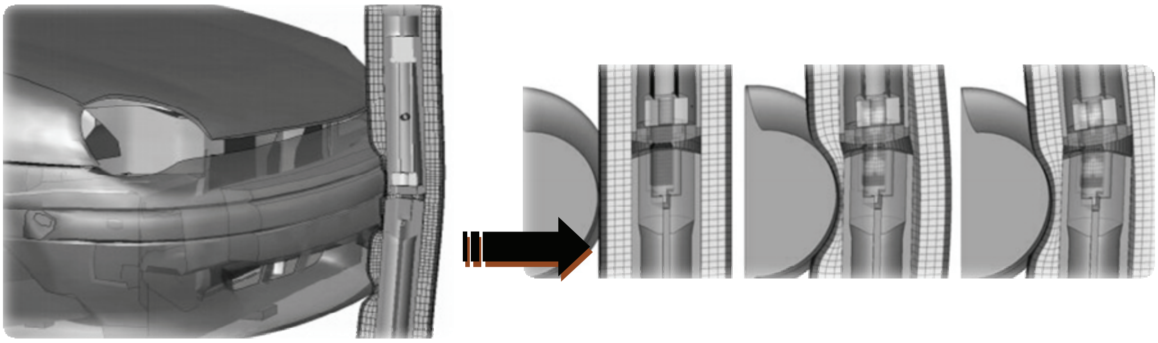

Fig. 3 Lower legform test and a knee joint close-up [9]

**Pedestrian frontal protection system**

Frontal protection systems (FPS also known as "bull bars") are popular among the SUV. Since the general number of these vehicles has recently increased on urban roads it became compulsory to test the FPS against the (EC) No. 78/2009 Regulation and Directive 2005/66/EC[1]. Basing on the legislation and studies, the lateral impact between the vehicle and a pedestrian was considered by the authors. Again, to gain the EC type-approval for the FPS the tests encompassing the vehicle with the FPS fitted must have been conducted. The complete model was virtually simulated under various dynamic conditions specified in the legislation. Explicit LS-DYNA code was used to verify the FPS performance against the limits. Fig.4 depicts the virtual model of the SUV front with FPS mounted, at two stages of the simulation with upper legform.

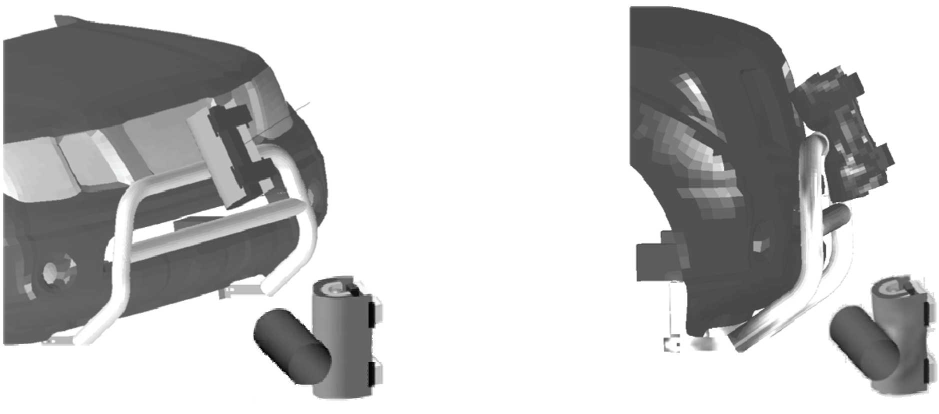

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Fig. 4 The FPS performance during the upper legform test: a) before impact b) during the impact

[1] The Regulation (EC) No. 78/2009 will be phased in beginning on 24 November 2009. However, the less demanding Directive 2005/66/EC relating only to frontal protections systems will be still valid to ensure the smooth transition between them- compare Section 11 of [8].

The optimal design of the FPS and its mounting was obtained after numerous tests. It is understandable that the physical test using various design alternatives would be more costly and time consuming, whereas the effective application field would be limited. On the other hand, the official EEVC document [1] indicates that the implementation of numerical simulation may meet some obstacles mainly of the legal and official certification nature. Therefore, a virtual test must be contrasted with physical test to validate the outputs. In fact, to gain the EC type-approved as well as national homologation a real impact test had to be carried out. However, the simulated acceleration has a similar shape and peak value as those in the physical test which indicates that the precision level of the model is acceptable.

**Conclusion**

One of the most challenging areas of vehicle safety engineering is pedestrian safety. It has been noticed that rapidly advancing technology in a field of vehicle occupant safety does not go hand in hand with the developments in passive safety of pedestrians. Pedestrian safety is an important consensus between many crucial factors such as car design and its frontal aggressiveness, roads and pavements layout, legislations (e.g. speed limitations), active and passive systems. The immense development of computation power and expansion of Finite Element Method enables to widen the possibilities and application area on the ground of pedestrian safety. The paper sets out how the virtual testing and FE-impactors can contribute in pedestrian safety improvements. The utilization of FE virtual simulations is continuously evolving, yet it still requires some accuracy enhancements, particularly in impactor and vehicle material modeling. Although the physical validation of a test tends to be expensive, it assesses whether potential development can be made to the simulation itself or to the vehicles.

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