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CYCLIST HEAD TO WINDSHIELD IMPACT ANALYSIS. DEFORMATION AND PERFORATION CASE STUDY

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Abstract: *Some particular types of accidents between motor vehicles and VRU produce partial intrusions of the VRU's body inside the passenger compartment through the vehicle's windshield. Collisions which result in windshield perforations can significantly alter the preconized human-body kinematics, throw distance and injuries, therefore making the reconstruction of the accident more difficult. Due to the complex nature of windshield deformations, the current state-of-art does not allow for the different stages of windshield deformation growth to be simulated in a multibody software. This paper presents a technique for simulating vehicle-VRU impacts with windshield perforations, comprised of locally altering the exterior contour of the vehicle's windshield damaged area, therefore being possible to simulate the intrusion inside the passenger compartment. A vehicle-cyclist crash-test which resulted in a 600 cm^2 windshield perforation and was simulated by applying the presented technique is exemplified as a case study in this paper. The results of the simulations yielded similar dummy kinematics, proving the viability of the presented technique for the kinematic sequence reconstruction of impacts with windshield perforations. An analysis of the influence yielded by the generation of a windscreen perforation over the VRU transport phase and throw distance was also conducted.*

Key-Words: *Cyclist impact, Windshield deformation, Windshield perforation, Multibody simulation.*

NOMENCLATURE

VRU: vulnerable road users

1. INTRODUCTION

Pedestrians and cyclists are regarded as vulnerable road users in traffic due to a high degree of exposure and a significant degree of susceptibility to serious and lethal injuries [3].

In order to improve VRU safety, the kinematic and dynamic behavior of a human body when subjected to an impact with a vehicle must be well comprehended. Accident reconstruction serves as a tool in establishing the causes which lead to an accident and also its effects. The accident reconstruction process is generally extensively conducted through multibody simulations, especially for accidents involving VRU, since the multibody approach offers significantly more data and elements of control than other reconstruction methods such as simplified mathematical models.

The multibody representation which consists of 20 individual articulated bodies is also more consistent in terms of biofidelity than other simplistic approximations.

Accidents between motorized vehicles and VRU are a common concern for forensics and researchers due to the frequently resulting severe or lethal injuries of VRU.

The most severe injuries are generated due to the head-windshield impact, such as skull and facial bone fractures, concussions or diffuse axonal injuries [1]. Depending on the impact configuration, eye injuries can also occur if the face of the VRU impacts the windshield.

Modern laminated windshields have better performances in terms of preventing lacerations and eye injuries compared to the early tempered windshields [2][4], which have been replaced in production for virtually all vehicles. Laminated glass has a composite structure with superior mechanical properties and better energy absorbing capabilities than single glass [10].

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The PVB interlayer which connects the sheets of laminated glass prevents glass destructuration into multiple large and sharp fragments due to its adhesive properties [10].
Another important safety aspect of the laminated windshields is given by the decreased chances of occupant ejection or VRU intrusion inside the passenger compartment through windshield perforation is prevented, due to their improved penetration resistance [7]. Yet at high impact velocities, depending on the angle between the VRU impacting body zone and the windshield, even laminated windshields may locally fail if the PVB interlayer is ruptured to a certain degree or if delamination occurs.
Delamination is a process which occurs when one or both sheets of windshield glass separate from the PVB interlayer [6]. Generically, windscreen delamination is caused by air entrapment during the fabrication phase or air/moisture admission during the exploitation phase [6].
There is also a natural tendency for laminated windshield failures to result as a windshield ages, since the adhesive properties of the PVB interlayer which connects the two sheets of glass diminish in time due to heat exposure [6]. Therefore, high vehicle impact velocities and windshield delamination can lead to perforations [5] in the windshield structure during impacts with VRU or occupants, as it is the case for older tempered windshields, resulting in intrusions in the passenger compartment.
This particular impact scenario is very difficult to recur in the virtual environment of available multibody software packages since the vehicle is generically represented as a rigid body and the windscreen stages of deformation can’t be simulated.
VRU kinematics are heavily influenced by intrusions in the passenger compartment.
The transport phase which begins after the first contact between the windshield and the head and lasts until the VRU is thrown off the vehicle [8] is significantly longer when windshield perforations are generated in the impact. Consequently, VRU throw distances are also increased and must be distinctively analyzed in relation to impacts without windscreen perforations.
This paper presents a vehicle-cyclist crash-test resulted in windscreen perforation which was simulated in the PC Crash multibody software and describes the used technique which can be applied to simulate any vehicle-VRU impacts with windshield perforations. Using the conditions obtained through the validated simulation and by generating an identical simulation but without perforating the windscreen, a comparative analysis between the cyclist kinematics was conducted in order to assess the influence of windscreen perforations over the transport phase and the resulting throw distance.

2. EXPERIMENTAL TESTING

A vehicle-cyclist crash-test was carried out using an anthropometric dummy, an Opel Corsa B vehicle and a regular bicycle. The dummy was maintained into stationary position with an electromagnetic gibbet support mechanism (shown in Figure 1) and released immediately prior the impact through the means of a laser detection system.

Figure 1. The crash-test scene and the gibbet support mechanism

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The vehicle was braked with a deceleration of 6.5m/s^2 and the vehicle impact velocity was 10.1 m/s.
The bicycle-dummy assembly was hit in the rear extremity by the front of the vehicle at a 00 impact angle. The lateral offset of the collision was 0.25 m.
The crash-test was recorded both with a Fastec HiSpec 5 high speed camera and with a drone.
The dummy was instrumented with a tri-axial accelerometer mounted inside the head's center of gravity in order to record head accelerations, which are shown in Figure 2.

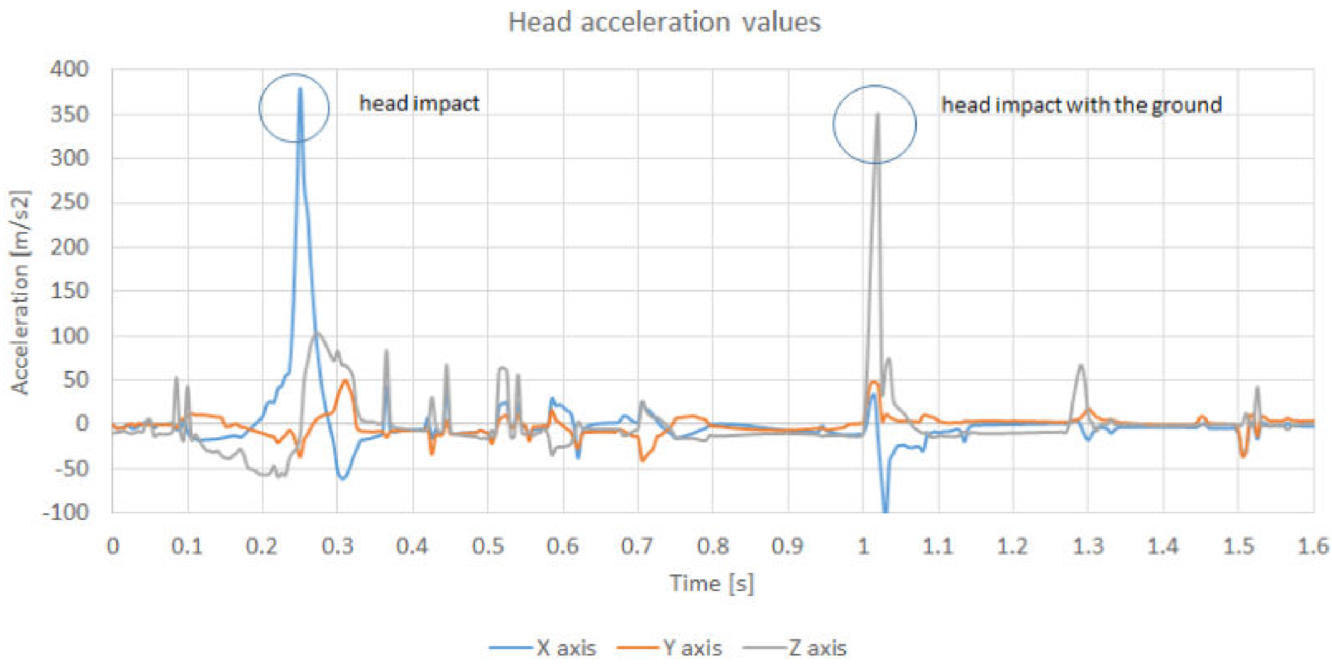

Figure 2. Head acceleration values recorded during the experimental testing

Upon the vehicle-dummy pelvis impact, the head of the dummy impacted the windscreen in the upper right corner, resulting in a perforated windscreen area of nearly 600 cm^2, shown in Figure 3. The length of the deformation measured along the windscreen is 0.45 m, with a corresponding width of 0.2 m.

Figure 3. The windscreen perforation which resulted in the carried-out crash-test

Literature indicates that windscreen perforation is the final stage of windscreen deformation [9]. Initially, a circumferential windscreen deformation is generated upon impact.
As the deformation energy is increased, the circumferential deformed area will record several axes of deformation linked to the center, similar to a spider web.
Upon reaching a threshold value of the deformation energy, the structure of the windscreen in the spider-web deformed area will fail, resulting in a perforation.

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The stages of windscreen deformation are presented in Figure 4.
This aspect was also observed for the carried-out crash-test as the perforated surface of the windscreen holds a distinctive spider-web type of deformation (shown in Figure 5), which is approximately concentric to the perimeter of the perforated surface.

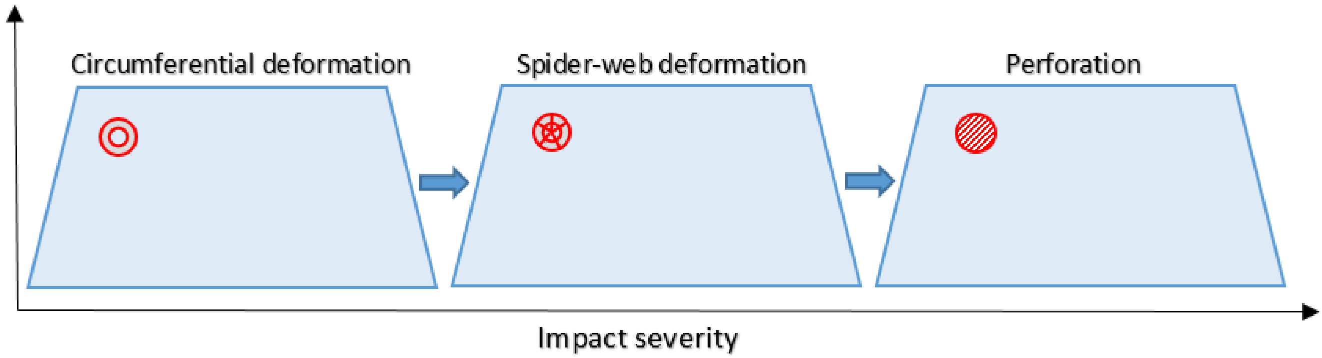

Figure 4. The stages of windscreen deformation [9]

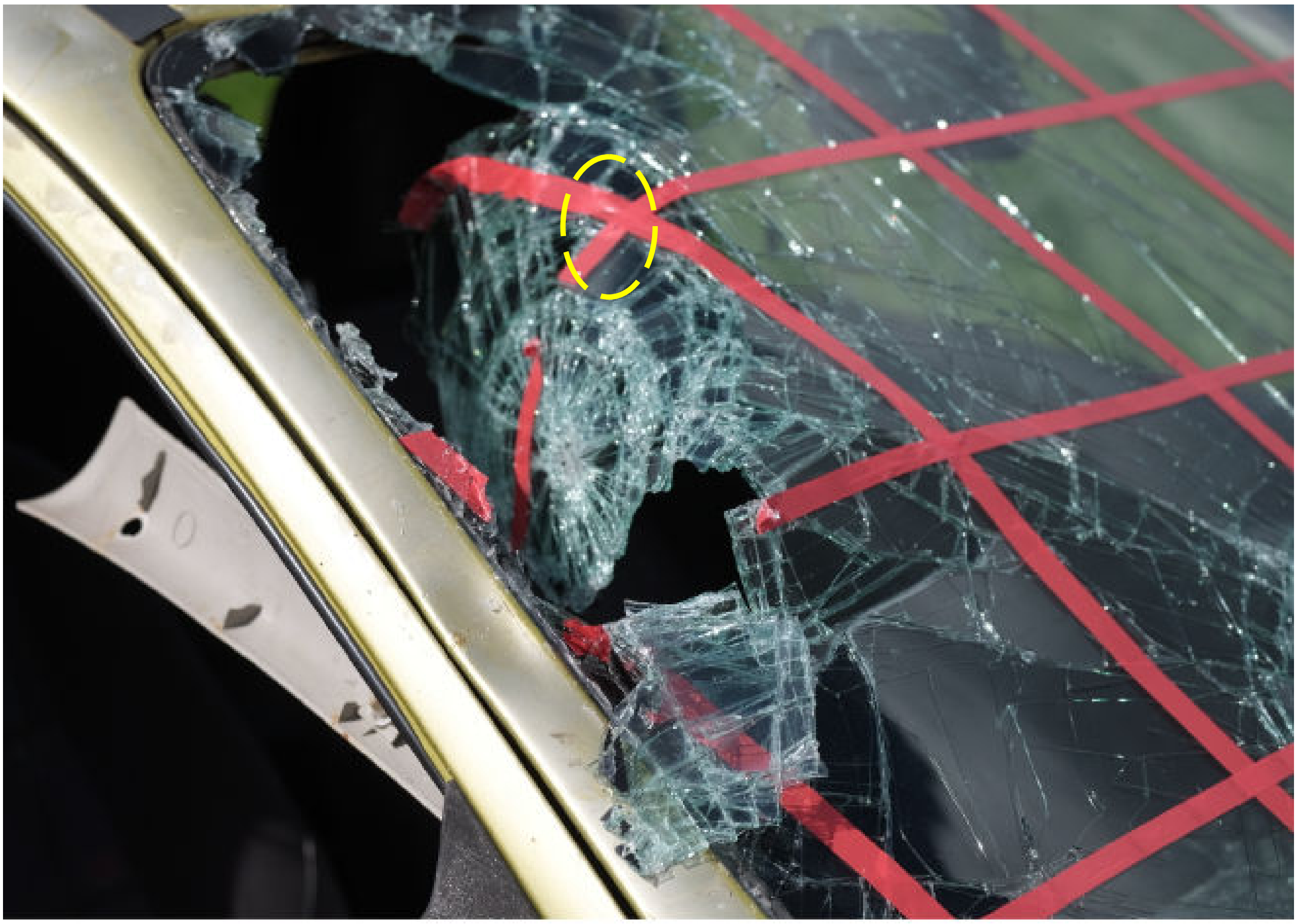

Figure 5. Spider-web type of deformation seen on the perforated area of the windscreen

3. METHOD FOR SIMULATING IMPACTS WITH WINDSCREEN PERFORATION

In order to properly analyze VRU impacts which result in windscreen perforations, simulations must be performed in a virtual environment.
Technically, for simulation software which rely on the multibody approach, such as PC Crash, vehicle deformations and their gradual evolution are virtually impossible to reproduce since the vehicle is considered a rigid body.

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Although circular and spider-web deformations can be neglected and still obtain accurate kinematics since the integrity of the windshield is not severely affected, this is not the case for windshield perforations.
However, it is possible to simulate VRU intrusions in the passenger compartment or unbelted occupant ejections, if the exterior contour of the vehicle is altered.
The shape of any vehicle in PC Crash is defined by a tridimensional triangulated contour stored in a separate DirectX file for nearly all existing vehicle models.
The simulation method is comprised of an ensemble of procedures meant to modify the default design of the vehicle’s frontal profile by inserting a cavity into the windshield in accordance with the configuration of the perforation.
The presented method was used to simulate the carried-out crash-test as it is shown further and it can be applied to any accident which results in windscreen perforations.
The first step consists in establishing the dimensional configuration of the perforation, which is done through the inspection and measurement of the windscreen’s deformation.
An important parameter is the space of intrusion travelled by the dummy inside the passenger compartment, which can only be determined through video analysis.
In the case of real accidents, the injuries recorded by the human body can indicate the depth of the intrusion by evaluating how further tissue lacerations are relatively positioned to the head.
The second step consists in inserting the default contour of the vehicle and simulating the impact after applying the required adjustments.
The insertion of the cavity into the windscreen (see Figure 7) is realized by drawing a polyline onto the lateral profile of the vehicle in accordance to the depth of the penetration determined through video analysis, followed by applying the extrusion function of the program, as shown in Figure 6.

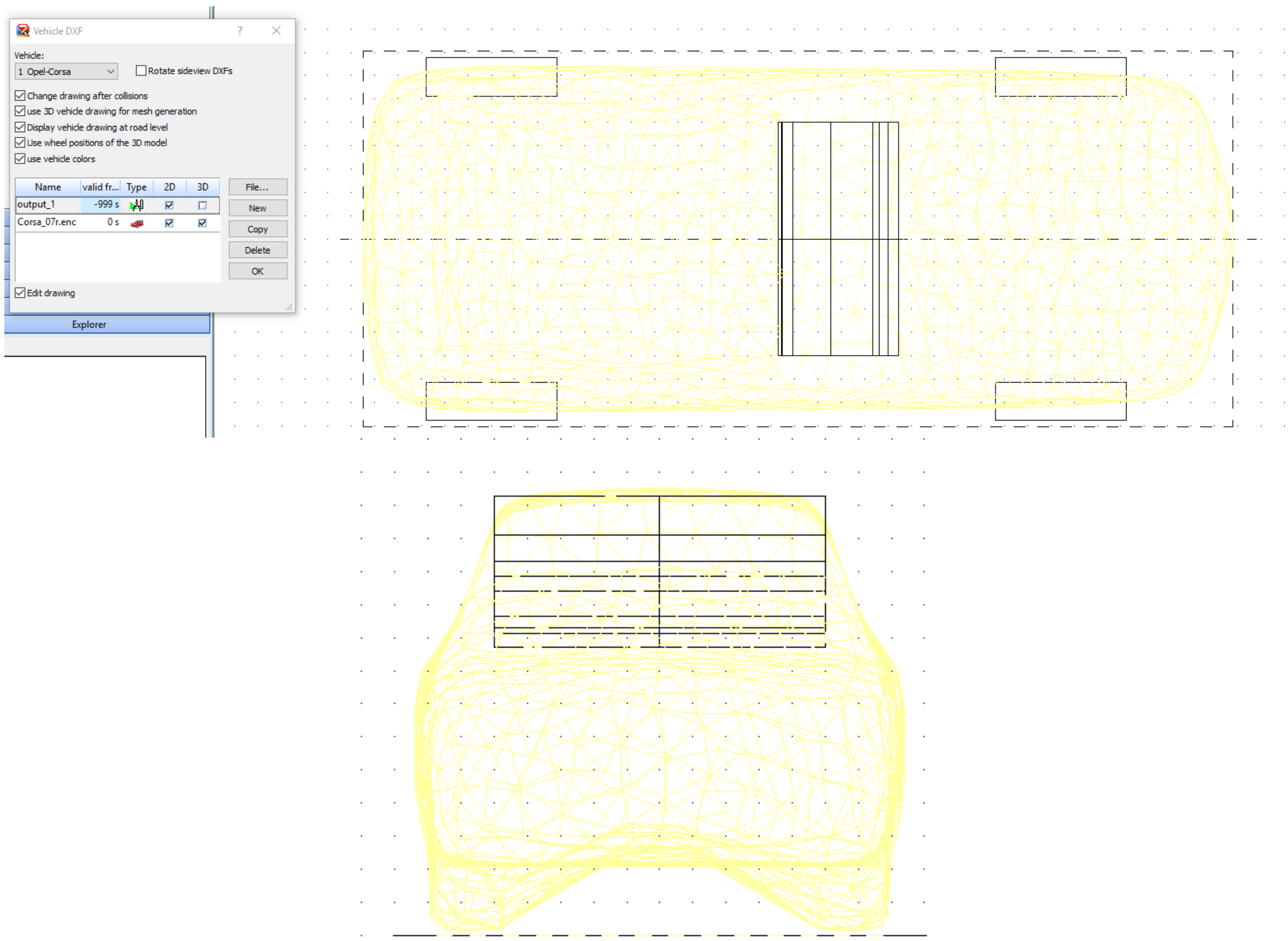

Figure 6. The extruded polyline marking the depth of the penetration

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Figure 7. The cavity in the vehicle's windshield obtained by applying the extrusion function

The final step consists in simulating the impact after inserting the multibody model of the cyclist-dummy assembly and adjusting the cyclist posture, as well as the dimensions and masses of the assembly.
A significant amount of iterations are required to determine the defining kinematic and impact parameters.
Firstly, vehicle velocity and deceleration are iterated until conformance since these parameters are not particularly influenced by the impact due to the significant differences in mass and velocity between the vehicle and the dummy.
Secondly, the orientation of the bicycle at the time of impact must be established in order to further eliminate unknown variables.
The analysis of the deformations recorded by the vehicle and bicycle can indicate the angle of impact with reasonable accuracy.
Since the crash-test was also recorded via a drone and a high-speed camera, the angle of impact between the vehicle and the bicycle was determined with certainty.
Finally, the impact parameters, as well as friction coefficients must be iterated until the simulation resembles the kinematic behavior of the dummy as described by the video recordings.
The simulation was validated by obtaining a good congruence between the kinematic phases of the simulation and the carried-out crash-test, as it is presented in Figure 8.
In order to determine the influence of windscreen perforations over cyclist kinematics, the experimentally validated simulation was modified by inserting a default profile for the vehicle, thus rendering null the previous windscreen alterations.
By analyzing cyclist kinematics for both impacts with and without windscreen perforation, it has been determined that the duration of the cyclist transport phase is over five times higher for the case with windscreen perforation than for the case without, as shown in Table 1.
The cyclist throw distance was increased by 23% for the case with windscreen perforation compared to the case without, yet for higher vehicle impact velocities it is possible that the difference would result higher.
There is also a possibility for cases in which the resulting throw distance is diminished, with further research needed to clarify this aspect.

4. CONCLUSION

Windscreen perforations occur in particular cases of vehicle-VRU impacts generated at high vehicle impact velocities or due to windscreen delamination. Current state-of-art does not allow for windscreen stages of deformation to be simulated in multibody software. The simulation method presented in the paper allows a good kinematic sequence reconstruction of vehicle-VRU accidents with windscreen perforations by altering the exterior contour of the vehicle, as exemplified in the experimental case study.

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The results of this study show that the generation of a windscreen perforation during an impact can increase the duration of the VRU's transport phase by over five times, which consequently increases the overall VRU throwing distance.

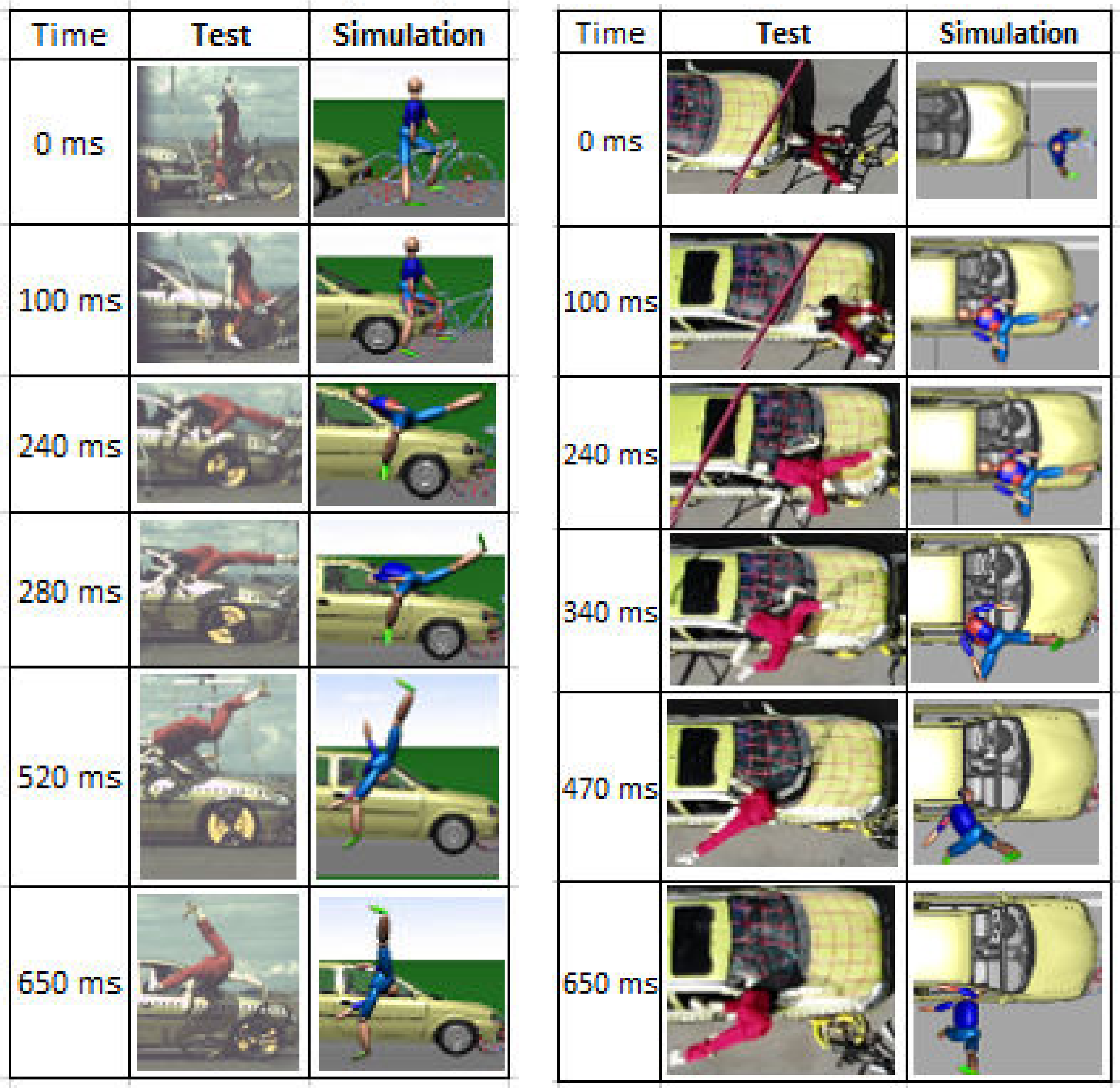

Figure 8. The kinematic phases of the carried-out crash-test and simulation

Table 1.
Cyclist transport phase duration for impacts with and without windscreen perforations

	With windscreen perforation	Without windscreen perforation
Head impact time (ms)	240	240
Launch moment (ms)	650	326
Transport phase duration (ms)	410	86

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