

PEDESTRIAN ACCIDENT SIMULATIONS METHODOLOGY USING DETAILED VEHICLE MODELS AND AGE-DEPENDENT LEG FRACTURE LIMITS ON THE PEDESTRIAN.

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ABSTRACT

This paper aims to define a methodology to perform pedestrian accident simulations with multibody techniques using a detailed geometry and stiffness characterization in the impacting vehicles as well as age dependant fracture limits for the MADYMO human pedestrian legs. This methodology is applied to real world pedestrian accidents reconstructed by UPM-INSIA in the frame of the APROSYS project (TIP3-CT-2004-506503) to show its benefits. The proposed methodology is shown to be more accurate than the current multibody simulations but without the model complexity and computational time requirements of the FE models.

Keywords: Pedestrians, MADYMO, multibody, accident reconstruction.

MULTIBODY SIMULATIONS of pedestrian impacts have been extensively used and improved through the years to enhance the pedestrian protection (Wismans 1982 to Van Hoof 2003). However, a non-uniform approach has been followed to consider the dynamic behaviour of the car in case of braking, the heterogeneous stiffness of the vehicle front end and the variability of the pedestrians involved in the accidents. This paper presents an structured methodology to construct pedestrian accident models that accurately take into account the vehicle particularities in this kind of simulations as well as the pedestrian different characteristics regarding their tolerance to certain injuries.

METHODOLOGY TO CONSTRUCT THE SIMULATION MODEL

STEP 1: GEOMETRY & STIFFNESS OF THE VEHICLE MODEL

The vehicle geometry and stiffness determine the kinematics of the pedestrian in the accident. The implementation of the geometry of the vehicle as a facet surface allows an accurate definition of the front end geometry of the car. To get this geometry, the same vehicles to the ones involved in the accidents have been scanned with a 3D scanning device, obtaining splines of the vehicle front surfaces. A post process in CAD has transformed them into surfaces and meshed them to include in MADYMO.

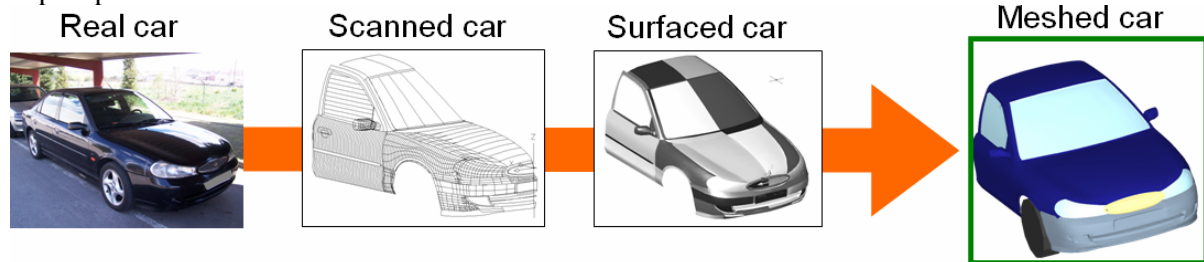


Fig. 1: Scan process followed to obtain the vehicle mesh.

The stiffnesses of the meshes, in their different parts, have been implemented as contact characteristics in a force-deflection form. To account for them, the stiffness corridors derived from the EuroNCAP pedestrian sub-system tests for the bumper, the bonnet and the windscreen base area from Martínez (2007a) have been used to map the stiffness of the different parts of the front end of each vehicle. These corridors define average force-deflection curves for the three levels of rating applied in the EuroNCAP pedestrian protocol; therefore they recommend an average red, yellow and green force-deflection characteristic for the bumper, the bonnet front, the middle and the rear part as well as for the windscreen base. To implement these contact characteristics along the front end of the car, the rating mapping published by EuroNCAP in their tested vehicles is used as guide to locate each contact characteristic in its corresponding EuroNCAP testing zone. With this approach, sixty different zones can be mapped in each car with a correct estimate of their local stiffness.

To take into account the areas not covered by the pedestrian EuroNCAP tests, basically the windscreen centre and the A-pillar, the values obtained by Mizuno (2000) are used for these two zones.

STEP 2: MULTIBODY FRAME OF THE VEHICLE MODEL

The chassis of the vehicle is represented by a simple multi-body frame consisting of a chassis body, linked with a free joint to the inertial space, plus four bodies representing each of the tyres, linked to the chassis body through a translational-revolute joint to allow the front and rear suspension work independently, (see figure 2) allowing the car to pitch if braking is considered or when it impacts the pedestrian.

The suspended mass of the vehicle and its inertial properties according McInnis (1997) are assigned to the chassis body, while the unsuspended mass with its inertial properties are assigned to each of the four tyre bodies.

The geometry of the vehicle, represented as a facet mesh, is supported to the chassis body, while the tyres are represented by ellipsoids with the diameter and width of the actual tyres of the vehicle.

The front and rear suspension stiffnesses are calculated with a simplified two degrees of freedom model considering the mass distribution in the front and rear axle of the car. For the tyre stiffness, Hooke's Law is applied considering the tyre loaded radius the 90% of its nominal radius (Vera 2003).

The front and rear suspension stiffnesses are implemented as characteristic load functions in the translational part of the translational revolute joints of the model, while the tyre stiffness is implemented as contact characteristic in their contact with the ground.

The initial deflection of the suspension model as well as the pitch of the car in braking is determined in two steps pre-simulation study with gravity and braking acting on the vehicle. With this preload of the suspension and the orientation of the chassis free joint, obtained in the braking pre-simulation, as input, the vehicle is positioned with respect to the ground in the real accident scenario.

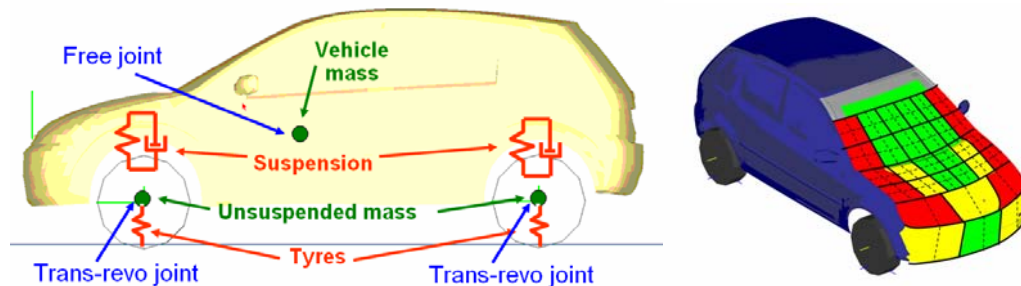


Fig. 2: Left: Multibody frame of the vehicle model. Right: Stiffness distribution in the vehicle front.

STEP 3: AGE DEPENDENCY FRACTURE LIMITS IN THE PEDESTRIAN MODEL.

It is widely documented that age has a significant influence in the human tissues properties and tolerance to impact (i.e. Zioupos 2001 and Carroll 2006). These effects are especially significant in the limits of the long bones to fracture, and therefore, this dependency needs to be implemented into the different pedestrian model sizes to predict further the leg injuries.

The MADYMO adult pedestrian reference human models (5% female and 50% and 95% male) are used to represent the pedestrians. These models have shown high correlation with PMHS test to estimate head impact velocities and positions on the vehicle surface and the fracture limits implemented in their legs (through measuring shear force and bending moments in locked joints along the leg) have successfully predicted the injuries found in the analysed PMHS tests (Van Hoof 2003). To represent the size characteristics of the pedestrian involved in the accidents, the reference model that is closest to the actual pedestrian measurement has been used. To represent the actual pedestrian age, the original fracture limits in the legs have been updated with the ones corresponding to its real age, obtained with the following procedure.

Taking into account the basics of the beam's theory, the failure stress in bending depends linearly with the applied load and the section modulus (Z), a purely geometrical parameter. Therefore, as the maximum bending stress is found to depend on age (Yamada, 1970), then, this dependency, as well as the 95% confidence intervals obtained, can be transferred to the maximum bending moment and the maximum shear force if no geometrical change is done in the model, therefore within the same reference MADYMO model (Figure 3), which, in this case will be the 5% female.

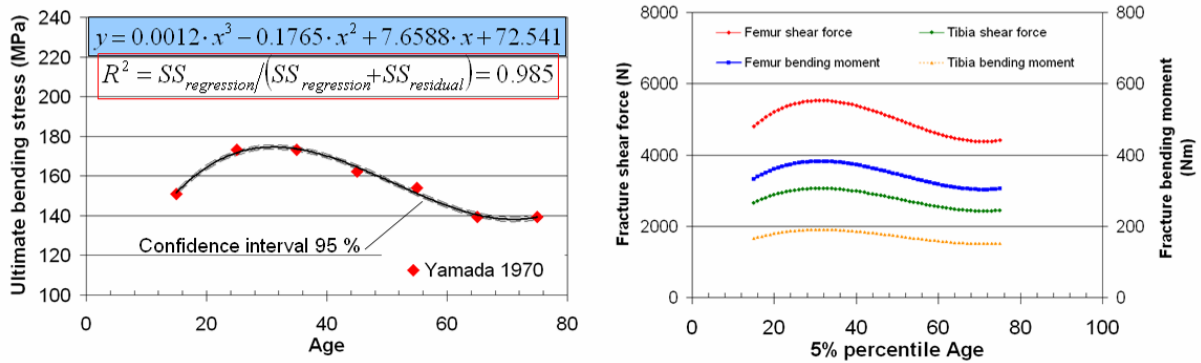


Fig. 3: Dependency of ultimate bending stress and the fracture limits in the legs with age.

PEDESTRIAN ACCIDENT RECONSTRUCTIONS RESULTS

	Case 1	Case 2
Vehicle	Ford Mondeo, 27 kph, braking	Skoda Octavia 28 kph, braking
Pedestrian	Female, 19 y.o, 1.60 m, 59 kg, walking, impacted in the left	Female, 65 y.o, 1.58m , 52 kg, walking, impacted in the leg
Injuries	Fracture femur R (AIS 851801.3), closed & displaced at proximal area. Fracture humerus R (AIS 2)	Fracture tibia and fibula L (AIS 853404.2 & AIS 851605.2), Knee dislocation L (AIS 850806.2) Occipital contusion (AIS 1), Cervical sprain (AIS 1)

Table 1: Accident scenarios description.

Two accidents have been selected with the next conditions: the vehicles are tested for pedestrians in EuroNCAP, the pedestrian suffered leg fractures and their age should be out of range of MADYMO pedestrian model validation. The two accidents have been modelled according the described methodology to reconstruct the real world accidents. Their details are summarized in table 1.

The approach followed has consisted of two steps. First, the simulations have been performed with the pedestrian fitted with age-dependency limit frangible legs. The recorded contact points in the accident scene have been matched with the model kinematics to obtain plausible reconstructions of the accidents. In these reconstructions, the fractures or not of the leg have been recorded. Once the kinematics was matched, the injury outputs have been compared with the real world observations. In this step, the frangible legs have been locked (no possible break) and the readings from the joints have been compared with the original and the age dependant model injury thresholds.



Fig. 4: Kinematics and contact point comparison.

CONTACT POINTS AND KINEMATICS

The kinematics of the pedestrian in the most plausible simulations are compared with the recorded impact points on the real world accidents, as seen in the figure 4.

In the first case, the dent above the vehicle right headlight and the skid marks on the bonnet match with the pedestrian upper leg impact and the sliding of the pedestrian along the bonnet. In the second case, the leg of the pedestrian impacts in the bumper corner, where no permanent deflection is recorded, and the occipital part of the head meet closely the windscreen impact on the car.

INJURY OUTCOME

The table 2 shows the comparison of the real world injuries and the ones predicted by the model in the legs. In both cases, leg fractures are predicted with the age-dependent injury threshold implemented, while the original threshold failed to predict them. Although the model predicts fractures associated

with two injury mechanisms (flexion and shear), there is not enough information in the collected data that allows to confirm that the different injury mechanisms predicted indeed occurred in the real cases. However, the big differences existing in the model results for the not predicted injury mechanisms with respect its tolerance limits suggest that the selected injury mechanism for each case is the most realistic one in generating the real injuries.

Case	Real world injury	Simulation results		Age-dep limits (with 95% confidence intervals)		Original limits	
		Shear kN	Bending Nm	Shear kN	Bending Nm	Shear kN	Bending Nm
1	Fract. of femur	5.21	99	5.13 (± 0.03)	355 (± 2)	5.5	380
				Predict upper leg fracture due to shear		Do not predict fracture	
	No fract. lower leg	1.99	173	2.84 (± 0.02)	178 (± 1)	3.04	190
				Do not predict fracture		Do not predict fracture	
2	No fract. upper leg	4.07	79	4.45 (± 0.03)	307 (± 2)	5.5	380
				Do not predict fracture		Do not predict fracture	
	Fract. of tibia and fibula	0.42	183	2.46 (± 0.02)	154 (± 1)	3.04	190
				Predict lower leg fracture due to bending		Do not predict fracture	

Table 2: Results from the simulation with the frangible leg locked compared with the tolerance levels.

CONCLUSIONS

Since a detailed geometry, an accurate stiffness distribution and a correct dynamic behaviour are implemented in the vehicle models, they are able to reproduce the kinematics of the pedestrian and, therefore, the orientations and velocities outputs from these kinematics are very valuable initial conditions for more detailed FE analyses on , i.e., head injuries.

Both accidents show many similarities in the scenarios and the pedestrian size but with a large difference in the age of the female pedestrian involved. With the age-dependent thresholds implemented for leg bone fractures, these models have shown up an upgraded capability to predict the top cause of leg injuries in real world (Isenberg, 1998) without the complexity of FE human models.

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