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AN OVERVIEW OF MADYMO USES AT INRETS

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Abstract

This paper describes the modelling approach using MADYMO 2D at INRETS (The french National Institute for Transport and Safety Research).

A mathematical dynamic model of the pedestrian leg in lateral impact was developed (M.MATYJEWSKI) to test car fronts in order to estimate the severity of the knee joint lesions and to predict the risk of leg injuries in car/pedestrian accidents. Results of this model were compared with those obtained with an instrumented mechanical leg used in the bumper impact test.

A train passenger behaviour during a crash at low speed was developed (J.BLOCH and F.MINNE) to improve the function of the fusible area at each carriage extremities. Results of this model were compared with those obtained during a real scale crash test.

The kinematic of a 3 years old child in a childseat on a passenger car seat is analysed (R.BIARD and J.L.CHANIAC) during a frontal impact. Experimental results from sled tests serve as a basis for the validation of the model.

Introduction

The Laboratory of Impacts and Biomechanics (L.C.B.) from INRETS used MADYMO 2D for several years. There is no question of describing all the research projects being carried out and we accordingly refer below to some examples of the results that have been obtained and the methodologies employed. We present mathematical models of ; firstly a pedestrian leg in lateral impact, secondly a train passenger behaviour during a crash at low speed and finally a children in a childseat on a passenger car seat in frontal impact.

MATHEMATICAL SIMULATION OF THE PEDESTRIAN LEG IN LATERAL IMPACT

Abstract

A mathematical dynamic model of the pedestrian leg in lateral impact (Bermond et al, 1992) was developed with the two dimensional MADYMO (Lupker et al, 1991) computer programs. This model will be used to test car fronts in order to estimate the severity of knee joint lesions and to predict the risk of leg injuries in car/pedestrian accidents. The effect of the bumper and the grill stiffness, of the bumper height and of the position and the value of the mass representing the upper body will be evaluated.

Results of this model were compared with those obtained with an instrumented mechanical leg used in the bumper impact test. This mechanical leg was developed by INRETS for a joint program involving several European research institutes, sponsored by the European Communities to evaluate the protection offered by a car in a pedestrian collision. The model was improved until

it minimizes the difference in the results of these two approaches.

Methodology

The analysis proposed is the one selected within the framework of a joint program carried out by several European research institutes, and supported by the European Economic Community. It consists in classifying the problems and entrusting each laboratory equipped with the appropriate means with the mission of studying and creating a system aimed at assessing the aggressiveness level of the different vehicle parts which are likely to impact the corresponding body segment of the impacted pedestrian.

Thus, from the beginning of the year 1990, the Laboratory of Impacts and Biomechanics of INRETS, in Bron, has been entrusted with the study and the development of :

- a leg provided with a biofidelic knee joint, at least as regards to global behaviour and stiffness under lateral loads which integrates high performance measurement systems and is able to transmit, for all the impact duration, the variation of kinematic parameters (angles, translations, accelerations, forces, etc...),
- a propulsion system allowing the reproduction of the leg impact on the front part of the vehicles tested,
- techniques, methods and calculation means enabling the acquisition, processing and interpretation of the parameters specific to such a research (Cesari et al, 1991).

A mathematical modelling of a pedestrian leg has been elaborated and optimized by comparing the results with those obtained with the instrumented mechanical leg in order to reproduce the car pedestrian impact conditions and to assess the effects of bumper height and stiffness, of the position and the value of the mass representing the upper part of the body.

Design and specifications of the leg/bumper subsystem

Taking into account the results of accident analysis and pedestrian biomechanical research, the following specifications were selected :

- Articulated mechanical leg.
- Free motion during the impact.
- Humanlike mass distribution between lower leg and thigh.
- Adult leg simulation.
- Biofidelic force/angle relationship for the knee.
- Measurement of bending and shearing deformation at the knee level.
- Measurement of lower leg acceleration.

A special knee joint was designed in order to correctly reproduce the mechanisms producing knee injuries, (figure 1). This knee is symmetrical in the horizontal and vertical planes. It consists of two main parts connected to the femur and the tibia respectively. Two deformable bars reproduce the biofidelic force/angle history. These square section bars are made of aluminium with a 6 mm diameter steel rod inside. This enables to record the slope of the force/angle history even in the permanent deformation zone of aluminium. The continuity

between the thigh and the lower leg is ensured by a rigid link articulated at each extremity.

For the test the mechanical leg is propelled by a small sled which is stopped just before the impact, and then the leg continues in a free motion. In fact during the free travel, because of the gravity effect, the mechanical leg moves also slightly down, but this can be accurately predicted by kinematic theory.

The mechanical model developed corresponds to an adult leg. The knee with the double articulation is also equipped with two identical deformation transducers. Each transducer measures the angle between the link and one of the two main extremities of the leg. Adding these two angles gives the variation in the angle between the thigh and lower leg. If the two angles have different values, this indicates that a shearing process was involved simultaneously with bending.

The measurement of the knee deformation enables the prediction of injuries in the knee area only. To check the protection provided against long bone fractures it is proposed to use the peak acceleration measured at the upper extremity of the tibia, which is directly related to the impact force caused by the bumper.

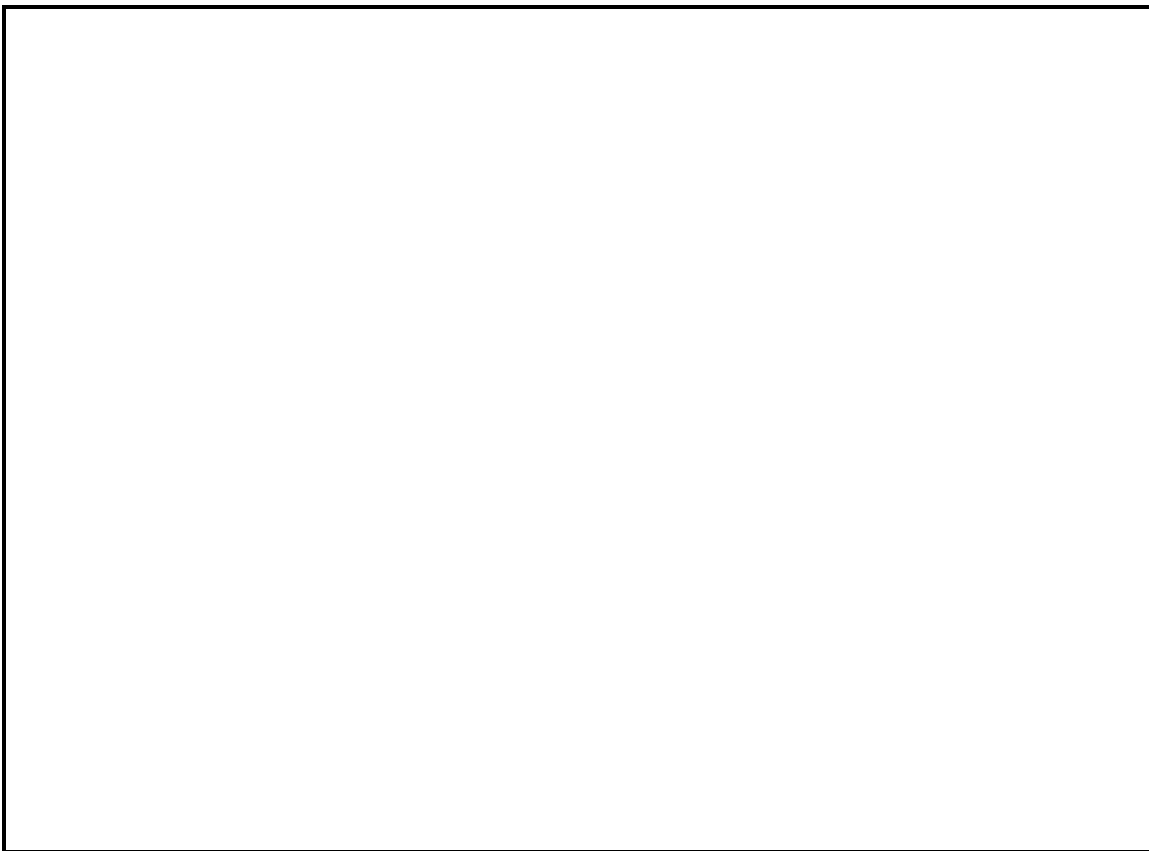


Figure 1 : Principle of the pedestrian knee mechanical model (Cesari et al, 1991).

Mechanical leg properties

Table 1 gives the main mechanical leg properties that were measured during dynamic tests.

	Weight	Length	Distance * CG/KJC	Inertia
	Kg	m	m	Kg m*m
Upper leg	8.7	0.42	0.218	0.079
Knee	0.35	0.09		0.00026
Lower leg	3.7	0.41	0.17	0.045
Foot	1.02	0.1	0.43	0.0008

Table 1 : Mechanical leg properties.

* CG : Center of gravity ; KJC : Knee Joint Center.

Leg mathematical model

The software used is the 4.3 version of the two-dimensional Madymo program (Lupker et al, 1991). The leg description is made by associating ellipses representing the mechanical leg such as the thigh, the knee (in fact the flexible beam in the knee joint), the lower part of the leg and the foot, linked by connecting elements (figure 2). For each component, we used the same properties as the mechanical leg (Weight, length, Distance center of gravity and the knee joint center and inertia).

We have measured the stiffness of the flexible beam in bending and shearing and the results obtained were used to define the stiffness of the joint between the knee/upper leg and the knee/lower leg.

To describe the car, we use the data available from Madymo databases (Madymo, 1990) (for example the stiffness of bumper, grill and hood). So, the front part of the vehicle is represented by one ellipse for the bumper and one for the grill and a plane for the hood.

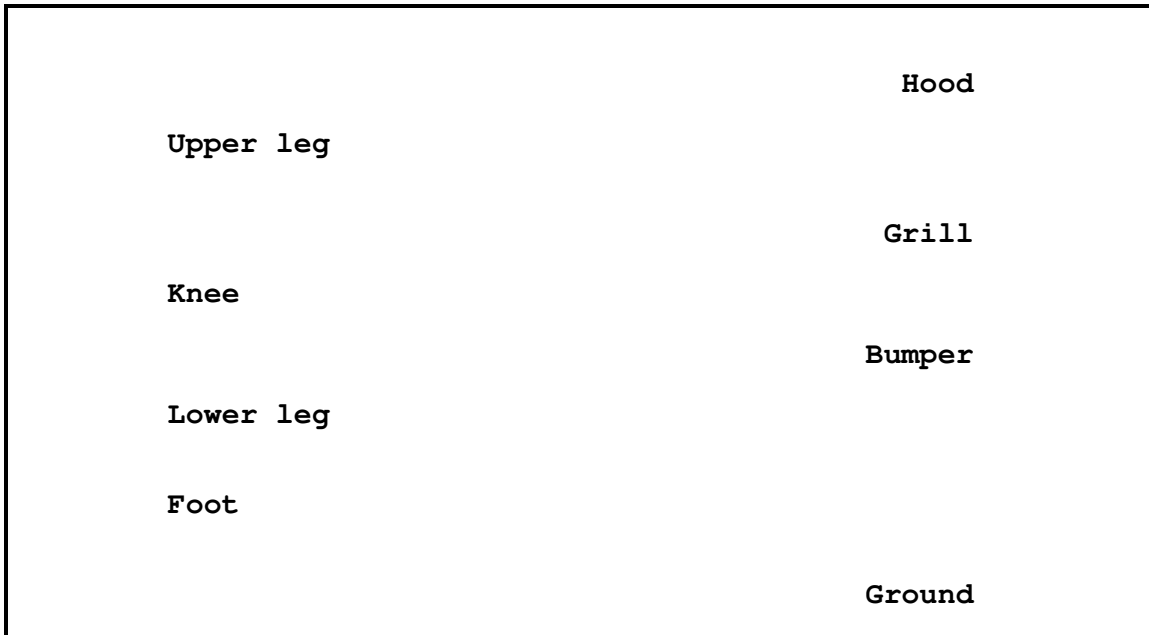


Figure 2 : The leg model with the front part of the vehicle.

We thus obtained a global kinematics of the leg impacted by the front part of a vehicle, acceleration curves of the tibia, femur and knee, force resultants at the leg/bumper contact level, tables of maximum and minimum angle values between two components, e.g. the upper and lower parts of the leg.

Under experimental conditions of the instrumented mechanical leg, modelling parameters have been optimized in order to

obtain results in accordance with the tests performed. The seven leg subsystem tests were performed with an impact velocity ranging between 30 and 32 kph (table 2).

During each test we have measured the angles between the knee link and the tibia and the femur, and the upper tibia acceleration in the direction of impact. A high speed video camera was also used. Seven tests were performed. The vertical distance between the knee and the bumper varied from -0.03 to 0.2 metres.

There is no ground friction in this model. Some additional Madymo simulations were made to confirm that ground friction has little influence on the knee joint angle. The reversal of the actual movements (car standing, leg moving) does not change the results significantly.

Test n°	Impact Speed km/h	* Vertical Offset (m)
GPI 01	29.24	+0.065
GPI 03	31.9	+0.090
GPI 04	31.9	0.000
GPI 05	28.9	-0.030
GPI 07	29.5	+0.020
GPI 08	29.6	+0.100
GPI 09	29.64	+0.195

Table 2 : Mechanical leg test conditions.

* Vertical Offset : Vertical distance between knee and bumper at impact.

The parameters to determine contact-interaction between the different parts of the leg and the car front are the main parameters which were tuned.

Results

We present the results when the vertical distance between the knee and the bumper is -0.200 metre.

Figure 3 illustrates kinematics after impact. The vehicle speed is 30 kph and the bumper is striking the lower leg during the first 20 ms and after, the grill hits the knee and the bonnet hits the upper leg.

Figure 4 shows the acceleration curves for the lower leg (tibia), the upper leg (femur) and the knee (center of gravity) as a function of the first 40 ms. The resultant force from the lower leg against the bumper is also presented. The highest acceleration values are located around 15 ms which correspond to the time of impact between the bumper and the lower leg. The values between the knee and the grill and between the upper leg and the hood located around the 28 ms are lower.

We present results for seven vertical distances between the knee and the bumper : -0.200 ; -0.100 ; -0.035 ; 0 ; 0.035 ; 0.100 ; 0.200 metre.

Table 3 gives the maximum values of knee acceleration and leg/knee contact forces. The knee acceleration is the most important when the bumper hits the knee. The leg/knee contact force is the most important when the bumper hits the upper leg.

Table 4 illustrates the maximum torques at the joint levels, upper leg/knee and knee/lower leg.

Table 5 presents the maximum and minimum values for relative angles between the knee and the upper or lower leg. The values are directly dependent on the vertical distance between the knee and the bumper. The smaller this distance is, the higher the results are.

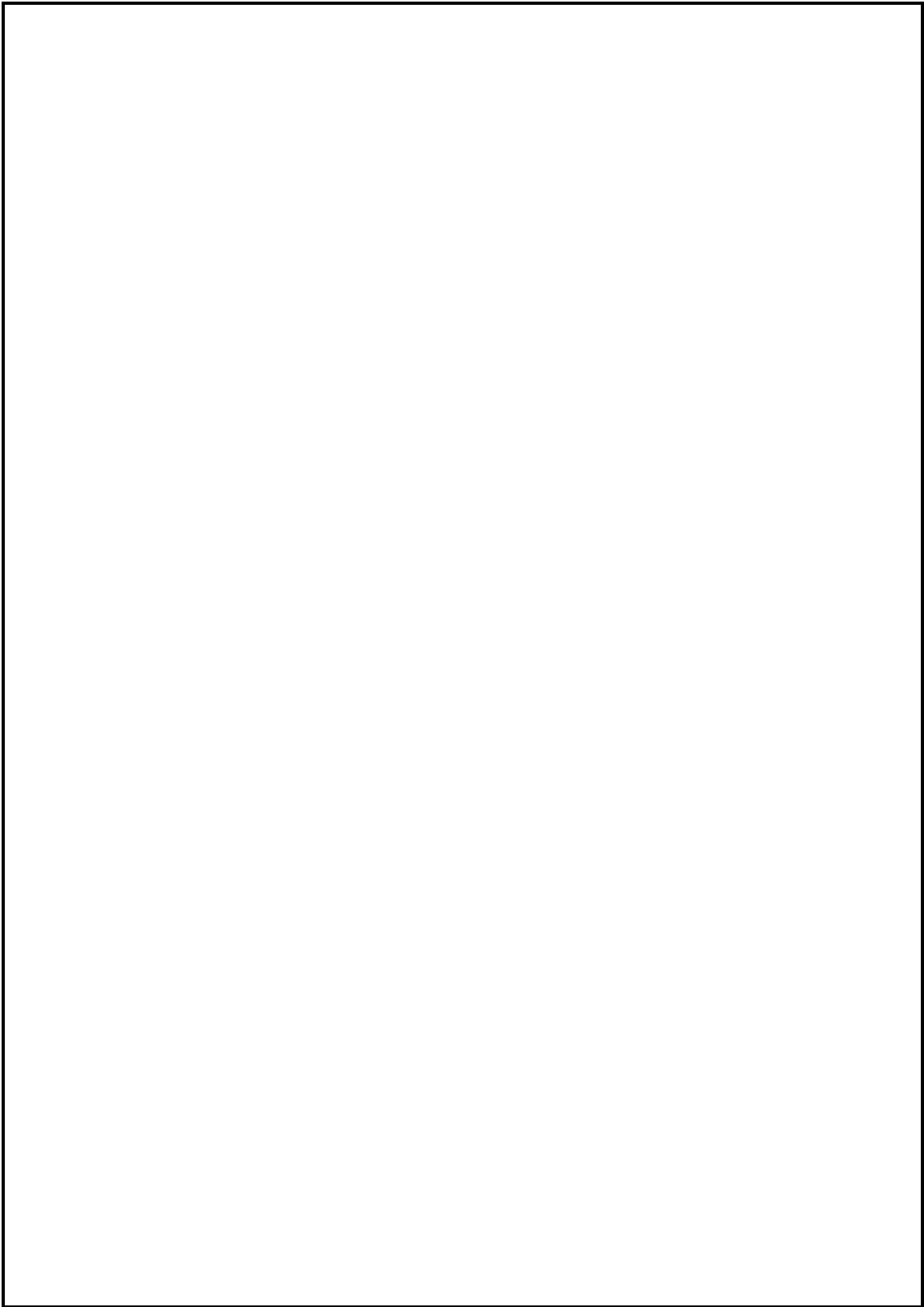


Figure 3 : Movement of the leg, vertical offset -0.2 metre.

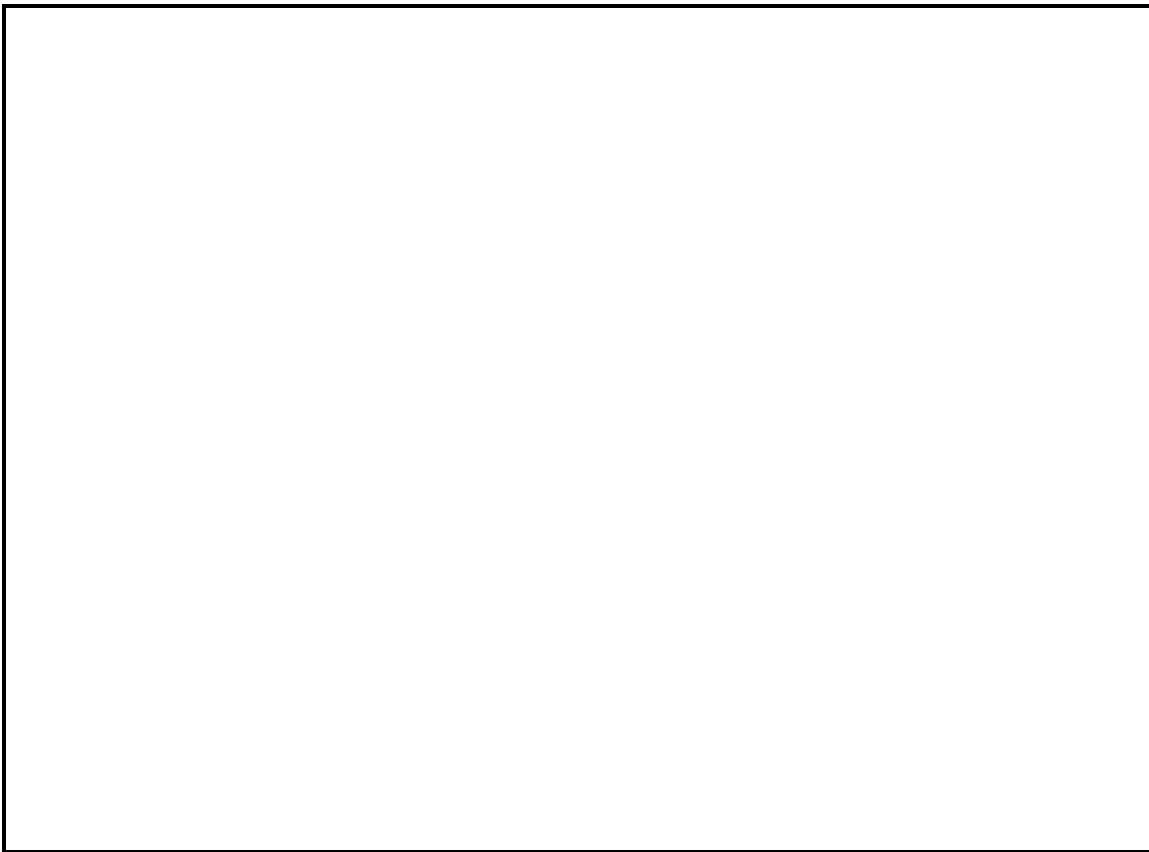


Figure 4 : Force and acceleration, vertical offset -0.2 metre.

* Vertical Offset (m)	Maximum resultant			
	Accelerations Knee (m/s**2) time (ms)		Force (N) time (ms)	
-0.200	628	12.95	Lower leg-Bumper 6537	14.37
-0.100	904	8.72	Lower leg-Bumper 7116	10.84
-0.035	1046	10.03	Knee-Bumper 5988	27.97
0	968	8.59	Knee-Bumper 6518	15.75
0.035	1149	8.16	Knee-Bumper 6049	13.81
0.100	828	7.75	Upper leg-Bumper 8111	19.87
0.200	513	11.52	Upper leg-Bumper 8061	18.30

Table 3 : Acceleration and force.

* Vertical Offset : Vertical distance between knee and bumper at impact.

* Vertical Offset (m)	Maximum / Minimum resultant torque			
	Knee-Upper leg (Nm) time (ms)		Knee-Lower leg (Nm) time (ms)	
-0.200	112	39.84	26	26.16
	-17	26.16	-94	15.09
-0.100	315	16.25	336	34.19
	-313	34.19	-461	16.37
-0.035	493	16.75	60	40.06
	-60	40.06	-610	13.66
0	573	13.97	3.29	2.12
	000	00.00	-542	15.28
0.035	619	12.44	3.38	2.94
	000	00.00	-544	15.87
0.100	494	20.62	411	37.91
	-406	37.97	358	24.81

0.200	139 19.93 -66 32.68	68 32.65 -84 22.80
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Table 4 : Maximum and minimum torque.

* Vertical Offset (m)	Maximum / Minimum relative joint angle			
	Knee-Upper leg (rad) time (ms)		Knee-Lower leg (rad) time (ms)	
-0.200	0.0020 27.03 -0.0147 40.03	0.0124 15.81 -0.0032 27.41		
-0.100	0.0399 35.06 -0.0418 17.22	0.1402 21.16 -0.0432 35.31		
-0.035	0.0005 4.06 -0.1703 23.94	0.2500 23.56 0.0000 00.00		
0	0.0000 00.00 -0.2452 23.47	0.2074 23.62 -0.0005 2.66		
0.035	0.0000 00.00 -0.2644 23.25	0.2168 23.91 -0.0003 3.34		
0.100	0.0577 40.03 -0.1918 25.09	0.0737 27.87 -0.0604 40.03		
0.200	0.0085 33.68 -0.0183 20.84	0.0109 23.65 -0.0087 33.68		

Table 5 : Maximum and minimum relative joint.

* Vertical Offset : Vertical distance between knee and bumper at impact.

This model is applicable for impacts below the knee joint. When the bumper impacts the leg impactor above the knee joint, contact force is applied close to the upper leg centre of mass, so rotation of the upper leg is small, the result of which is a smaller knee joint angle.

Conclusions

The aim of this research program was to evaluate the risk of pedestrian leg injuries when impacted by a car front. To achieve this aim, a mechanical instrumented leg was designed and its performance was evaluated.

The concept selected for this design has proved to work well : the deformations by bending and by shearing in the knee area and a force related parameter for lower leg impacts can be quantified.

Mathematical simulations show the capability of the mechanical leg to integrate the differences in shape and stiffness affecting the risk of injury, and this was confirmed by the tests performed.

The response of the soft tissue of the leg is not optimized. For this first step a standard dummy flesh was used ; however, it seems advisable to replace it by a less elastic foam, having a higher hysteresis. It will also be necessary to evaluate the repeatability, as well as the durability of the mechanical leg.

We still have to simulate other use conditions of the model as a function of the bumper and grill stiffness, as a function of the mass of the remaining body, as well as the vehicle speed influence.

Both aspects of modelling and development of an instrumented mechanical leg still require a lot of tests.

MATHEMATICAL SIMULATION OF A TRAIN PASSENGER IN FRONTAL IMPACT

Abstract

For developing any new method to construct a train with less consequence for the passenger when there is a crash, the researches being carried out at the L.C.B. are the structural behaviour of the train and biomechanical response of the passenger. In this paper only the second part is described. The results of the model are compared with those obtained with Hybrid II in a real scale crash test.

Real scale crash

There were three carriages ; one in movement and two stopped. The carriage the farther of the impact point, contained 4 dummies ; 4 Hybrid II equipped with accelerometers in the head, the thorax and the pelvis. Two high speed cameras film the behaviour of the dummies.

The train hitting weights 200 000 kg and the train hitted weights 400 000 kg. The speed at the impact was 30 kph.

Mathematical Model

The passenger

The mathematical model (figure 5) was applied to the dummy seated forward facing the impact. We choose the input file from the MADYMO 2D Data bases (Madymo, 1990). We change the values for the angles to put the Hybrid II in a seat.

The whole seat

The seat is also described. It gives the geometric characteristics as the seat for the first class in a "Corail carriage" and the material characteristics of the seat are measured. We made the assumptions that the seat is rigid. It weights 32 kg. Its inertia is negligible (0.0001 kg.m²) because it does not contribute for a rectilinear movement from the seat to the ground.

The whole seat has to be in plan/plan contact with the ground in order to describe a rectilinear movement. Two ellipses are connected with the floor to define a plan/plan contact with two points. Each ellipse has got a mass, 19 225 kg which is the half weigth of a train and a inertia is negligible as for the seat.

We consider that the floor is rigid and we take the material characteristics from the Madymo Databases and Application (Madymo, 1990).

The ground

The ground is indeformable and represented such as an infinite plan.

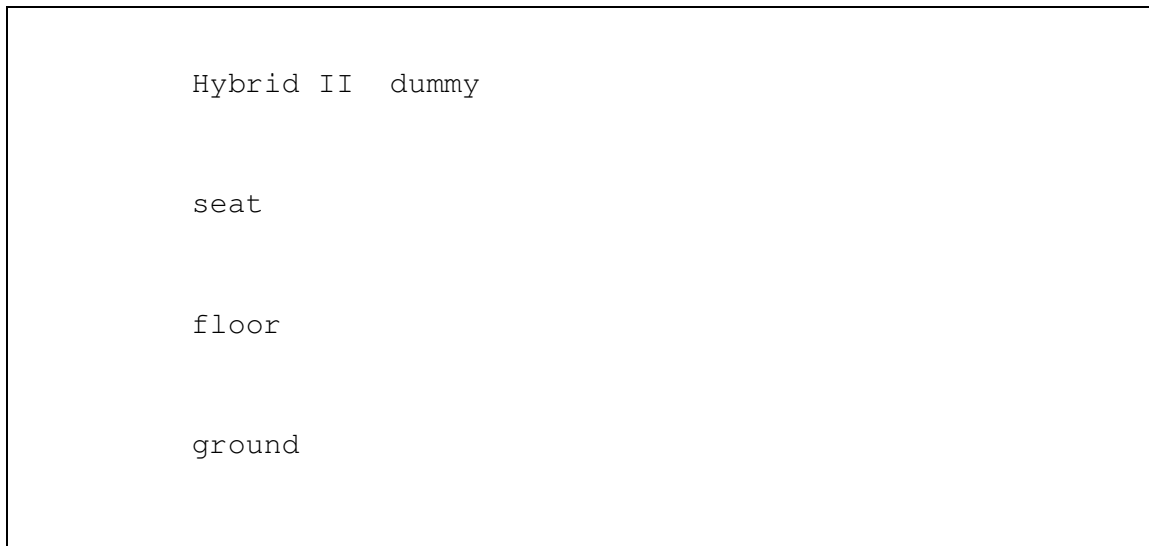


Figure 5 : Passenger train model.

Validation and results

The model was decelerated ; the same law than the real scale crash (one point each 7.5 ms for the first seconde and one point each 32.5 ms until 1.5 seconds) and we put also the gravity acceleration.

The calculation was done from 0 to 1.5 second. The time step is $10E-4$ with RUNGE KUTTA degre 5. We store the results for the displacement and acceleration each 100 step.

The curves in figure 6 show the comparison between the acceleration measured during the test and those obtained from the mathematical model. In figure 7, we present the curves in X direction (direction of the eyes from the dummy).

Figure 8 illustrates the kinematics after the impact.

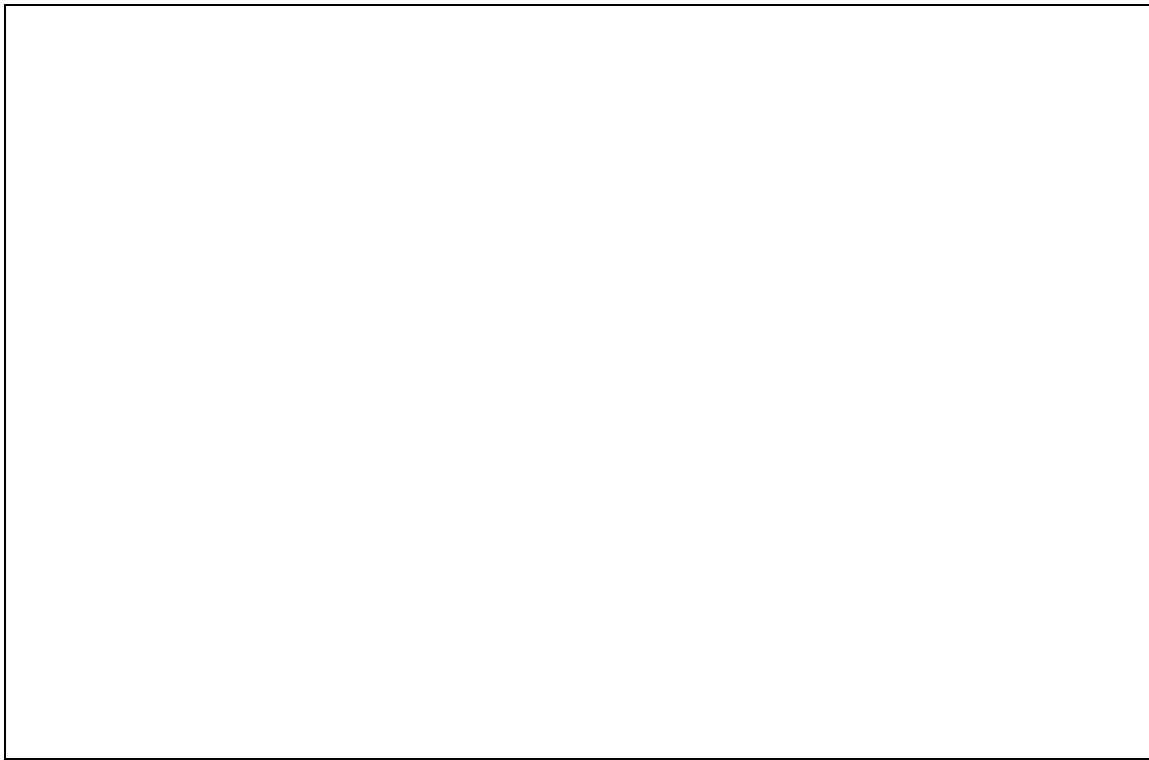


Figure 6 : Pelvis acceleration in the direction of X.

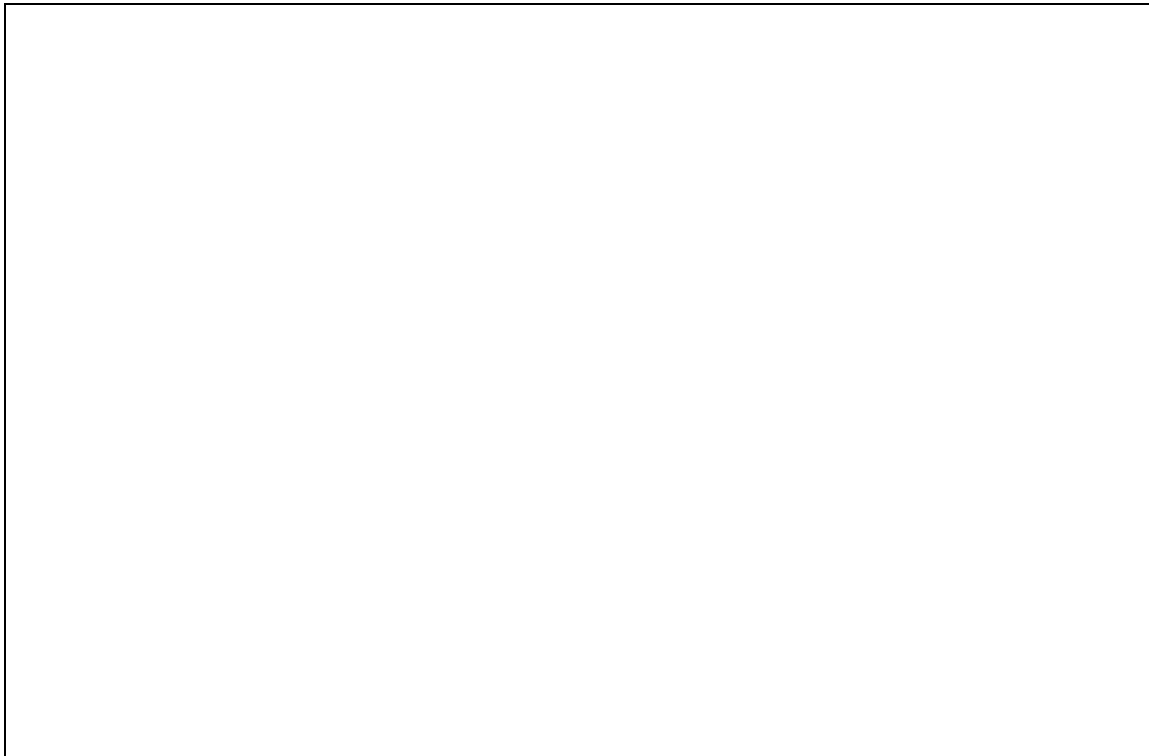


Figure 7 : Head acceleration in the direction of X.

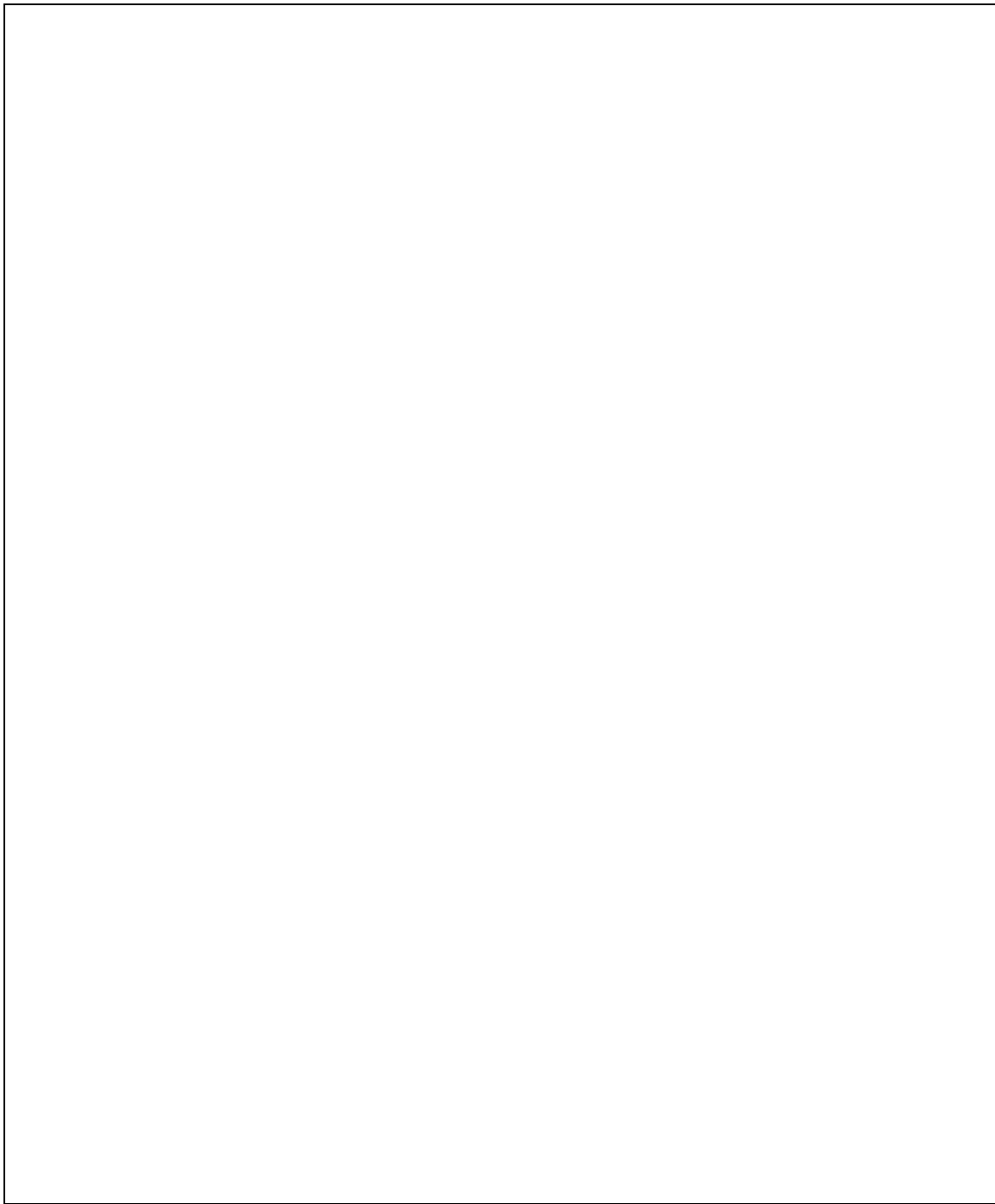


Figure 8 : Movement of the dummy.

Conclusion

A modelisation included a lot of parameters, for the dummy and the seat and the contacts between each other. Results from sled tests, now in progress at INRETS will be compare this mathematical simulation still in improvement.

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References

F. Bermond, D. Cesari, F. Alonzo, M. Matyjewski. *Mathematical Simulation of the Pedestrian Leg in Lateral Impact.* Proceedings of the 1992 International IRCOBI Conference on the Biomechanics of Impacts, Verona, Italy, September 9-11, 1992, pp 61-72.

D. Cesari, F. Alonzo, M. Matyjewski. *Subsystem test for Pedestrian Lower Leg and Knee Protection.* Proceedings of the Thirteenth International Technical Conference on Experimental Safety Vehicles, Paris, France, November 4-7, 1991, 91-S3-O-08.

H.A. Lupker, P.J.A. de Coo, J.J. Nieboer, J. Wismans. *Advances in Madymo Crash Simulations.* International Congress and Exposition, Detroit, Michigan, February 25 - March 1, 1991, SAE SP-851, 910879, pp 135-146.

MADYMO Databases and Applications. Version 4.3 (Avril 1990), TNO Road-Vehicles Research Institute The Hague, the Netherlands, Department of Injury Prevention.