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PEDESTRIAN CRASH – LEG/FRONT BUMPER ANALYSIS

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ABSTRACT

In the car industry, occupant safety has been in the spotlight of the media for some time already; a better EuroNCAP rating can make the difference between two competing models on the same market from the point of view of the customer.
Not as well developed as occupant safety, pedestrian protection is becoming more and more a concern of both car manufacturers and European Governments. One of the reasons is the increasing number of accidents in which pedestrians are involved. This is why the number of requirements with which a car has to comply will increase in the following years, taking pedestrian protection to a higher level.
This paper focuses on one specific type of crash in the pedestrian safety domain: legform - front bumper crash. For this purpose, a practical application of numerical simulation and an example of correlation with results of real tests will be presented in the following pages. The car model, which is used as an example, is the New Renault Laguna (2007)."

KEYWORDS: numerical simulation, crash, pedestrian

1. SAFETY IN CAR INDUSTRY

In the automotive industry, one usually distinguishes:
Active safety systems: equipment that is designed to prevent an accident from happening.
We can include here *emergency brake assist (EBA), anti-lock blocking system (ABS), electronic stability control (ESP), electronic brake force distribution (EBD) etc.*

Passive safety systems: here we can find all car equipment whose purpose is to reduce injuries as much as possible during and after a crash. We can include: *seatbelts*, *airbags*, zones designed to absorb and dissipate the energy of a collision, *steering columns*, which collapse during the crash and *pedestrian protection systems*.

2. PEDESTRIAN PROTECTION SYSTEMS

The majority of pedestrian crashes involve a forward moving car. In this type of crash, the pedestrian suffers an impact first from the car then from the fall to the ground.
Over the years, it has been noticed that most fatal injuries occur due to the impact of the car, thus vehicle designers are focusing their attention more and more on understanding and improving the car-pedestrian interaction.
Medical research [1] shows that in the case of a pedestrian crash, the rate of mortality relative to the speed of the car is shown in Fig 1.

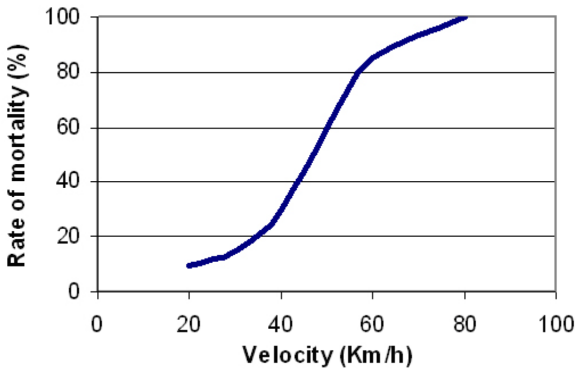

Fig. 1. Rate of mortality vs velocity

A pedestrian crash can usually be divided into 4 stages:

1. Car Impact: Front-bumper vs Leg
2. Car Impact: Front edge of the hood vs Upper thigh/pelvis
3. Car Impact: windshield / hood vs Head
4. The pedestrian is projected in the air and hits the ground.

So, in the case of a “classical” collision between a car and an adult pedestrian, the front bumper hits the lower part of the legs (knee, tibia), then the upper thigh or pelvis hits the front part of the hood, inducing a rotating motion of the pedestrian. This leads to the final impact with the hood or the shield of the car before being thrown into the air and hitting the ground.

Brain trauma appears when the head hits a rigid surface (hood) and the value of acceleration of the brain is superior to the maximum value which it can withstand.[1]

The main injuries from a pedestrian crash include the rupture of the knee ligaments, tibia and femur bone breaking.

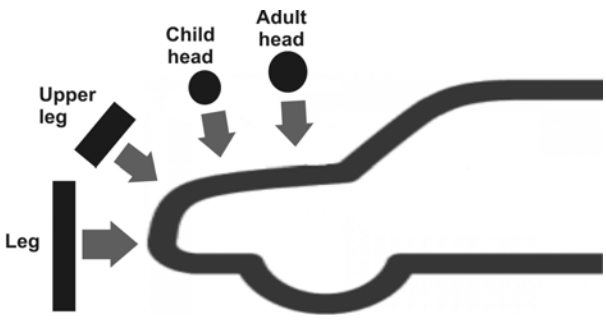

Fig. 2. Pedestrian crash

In order to minimize the injuries in a pedestrian crash, one should work on the 4 following types of impact : leg-front bumper, upper leg-front hood, child head – hood and adult head - hood (Fig. 2). This paper will deal with the first of the four types, the leg-front bumper crash.

3. NUMERICAL SIMULATION

In recent years, with the help of advanced development of software and hardware equipment for numerical simulation, the time in which a project is finished and a new car is launched on the market has become smaller and smaller. The competition in the automobile market has lead constructors to seek, apply and improve the latest techniques in car manufacturing.

Due to the higher needs of project development as cost-effective and rapid as possible, the numerical simulation has gained more and more terrain. After it is manufactured, a car has to pass first the requirements of the homologation agencies, then the very popular ranking tests (EuroNCAP). Potential problems, which can affect the quality of the product over its life are identified and removed during the project phase.

If we take for example the front bumper of the New Laguna (2007), the design needs to comply with several other requirements in addition to pedestrian safety. In order to achieve this, two numerical simulations are intensively used:

1. Simulation of the injection process.

This is done to check if there are flaws in the manufacturing process that can appear (visible weld lines, uneven color zones etc). The supplier has the responsability of doing these simulations; the most commonly used software being MOLDFLOW, by Autodesk.

2. Simulation of the behavior of the bumper after it is mounted on the car.

Here, the bumper has to undergo many virtual tests, such as intense heat due to sun exposure, frontal crash, pedestrian crash, static loading etc. For this purpose, Renault uses software like PAMCRASH and ABAQUS, only to name a few.

By virtual prototyping and numerical simulation, we can improve the performance and the cost of the part before is it actually built. A physical test is carried out in addition to the numerical one in order to validate that the part meets the desired requirements. In conclusion, the need to build several sets of physical prototypes of the parts has decreased to a very small number, thus saving time and money.

The advantage of numerical simulation over the physical test is that, rather than following a costly testing procedure and waiting between the test and the post-processing of the results, in numerical simulation we can immediately see if one part of the assembly does not comply with the specifications. Thus, we can define the needed adjustments and rerun the simulation until we obtain the desired results.

More precisely, while waiting several days for the physical test results for one crash configuration, we can numerically test hundreds of parameters at the same time while observing in real time the global effects. If we see that with the current front bumper design it is impossible to attain the required performances, a geometry change can be proposed.

Besides working with the geometry specifications, we can run numerical tests to find the optimal thickness of the front bumper. If a stiffer front bumper is needed to limit the indentation of the legform to avoid contact with the Danner crossmember, several tests will be made in order to obtain the desired value. In the same time, we need to be careful not to overestimate this value, knowing that an increase by 0,5mm in thickness can lead to 10-15% increase in mass. Overestimation must be avoided as the total mass of the vehicle has a direct impact on fuel consumption, which is a very important criteria for the customers.

Another important parameter is the material of the front bumper. While for some models, well-known materials are used (like polypropylene), for others the behavioral characteristics of the material are kept confidential by the supplier. In these cases, in order to integrate the bumper performance in frontal crashes, encrypted material is used.

[1] Renault internal documentation

4. LEG-FRONT BUMPER IMPACT

The standard regulation criteria a car must respect in order to insure that the tibia is not broken and the knee is not severely damaged are:
- tibia maximum acceleration, a < 150g
-maximum displacement of the knee: d<6mm
- the dynamic bending angle: f<15°

In Fig 3 we have a graphical representation of these biomechanical criteria: the acceleration of the legform, the displacement of the thighbone with respect to the tibia bone and the rotation of the femur with respect to the tibia.

In order to increase the overall safety level of the cars, Renault is equally concerned by occupant and pedestrian safety. However, at the same time, the car needs to comply with other "classic accidents" such as parking low speed crash and repair capability crash.

The pedestrian crash is in permanent "conflict" with other standard tests of the front bumper: the parking crash at low velocity (4km/h) and the repair capability crash (16 km/h). While for a pedestrian crash, we must have a soft bumper to avoid bone damage, for the other two we must have a rigid bumper to limit the damage of the steel structure. Therefore, for the pedestrian crash, elements whose aim is to absorb the energy of impact have been developed. Behind the bumper, a new element can be currently found: the "pedestrian absorber".

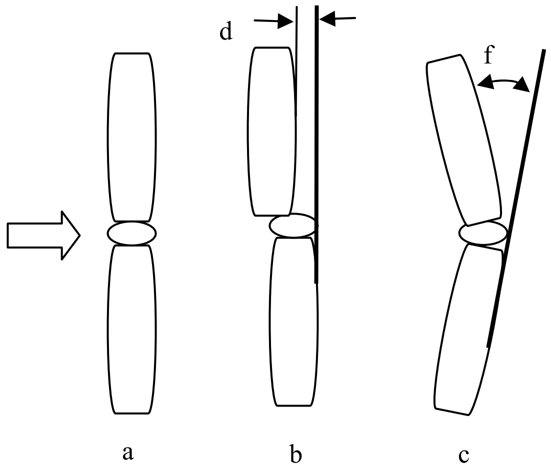

Fig. 3. Legform criteria: a) Acceleration;
b) Max displacement c) Dynamic bending.

When the pedestrian crash occurs, the front bumper breaks and the energy is absorbed by this element. To respect the criteria of the other two types of crashes (no damage to steel structure), another rigid element has been added behind the absorber: "the Danner crossmember[2]", which is connected to the "sidemembers[3]".

Therefore, the key part is the "absorber", which has been introduced between the front bumper and "the Danner crossmember". This part is made of an "alveolar structure" and has a foam-like behavior.

Another factor to take into consideration is the height of the bumper: a most desirable situation is that the front bumper hit the leg well below the knee.

This is because, when considering the consequences, knee surgery is much more complex operation than repairing a broken tibia.

The front bumper is always limited by geometrical constraints in order to respect all the biomechanical criteria. This is why front bumper absorbers are needed; these are divided into "upper absorber" and "lower absorber", the latter being usually more rigid, made of plastic (Fig. 4).

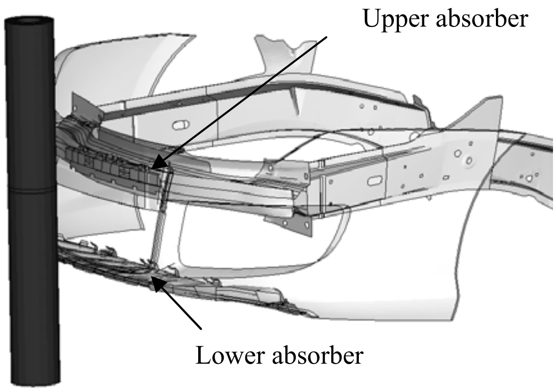

Fig. 4. Front bumper absorbers

For instance, if the stiffness of the lower absorber is decreased compare to the upper one, the leg will have the tendency to slip under the car.

Finding technical solutions in order that a car obtains the maximum score in EuroNCAP tests is possible today thanks to many years of theoretical studies and practical tests.

5. PAMCRASH SIMULATION

5.1. General features of the FE model

General features of the Pamcrash model used in the simulation:

- number of elements: ~150 000 shell/~10 000 solid
- ~200 contacts defined between parts involved in the crash.
- ~ 30h of server computing time

5.2. FE model: construction and boundary conditions

For this type of simulation, we have the following boundary conditions:

-The legform is oriented in the same way as the real human leg during the impact.

-The positioning of the legform on the vertical axis is standard, but the point at which it first touches the car depends on the car model. For hatchback type, the impact point is situated at the level of the upper absorbers. For SUV's, the knee will impact the car in the front grid.

-The movement axis of the impactor is parallel to the longitudinal axe of the vehicle;

-The knee joint is modeled with spring-type links having a very similar behavior to a real human leg.

-Because the front bumper geometry is different along a transversal axis, it is necessary to test several points of impact to be sure, that no matter in what position the accident occurs, the criteria are always respected. If the crash occurs on the left or on the right extremity of the bumper, another part will affect the performance: the headlights. In order to limit their influence, some headlight attachments are designed to break after reaching a certain level of stress.

Beside the analysis of the biomechanical criteria, another factor to study is the energy absorbed by the bumper and the absorber.
The kinetic energy of the legform which needs to be absorbed is:

M=13,6Kg (standard mass)
V=40km/h (standard velocity)

$$E_{kinetic} = \cdot \frac{m \cdot v^2}{2} = \frac{13600g \cdot (1{,}11mm/ms)^2}{2} = 854J$$

This energy is absorbed by the front part of the car. A typical distribution is usually 45% for the absorber, 35% for the front bumper and 20% for other parts.

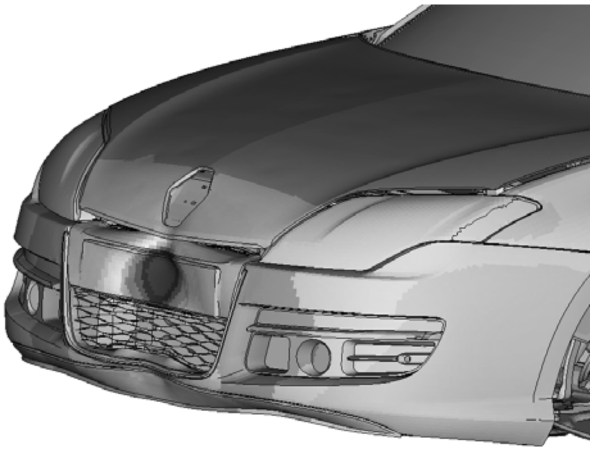

Fig. 5 Front view of the impact zone

In Fig 5 we have a photo where we can observe the performance of the car during the crash: we can notice the indentation of the legform into the front bumper, and the corresponding deformation of the bumper.

5.2. Simulation results

In Fig. 6 we can see that the maximum value of acceleration is 142 g, well under the regulation limit. In the acceleration of the leg-form we can see two peaks:

-the first corresponds to the contact between the legform and the lower part of the front bumper;

-the second corresponds to the contact between the legform and the upper part of the front bumper.

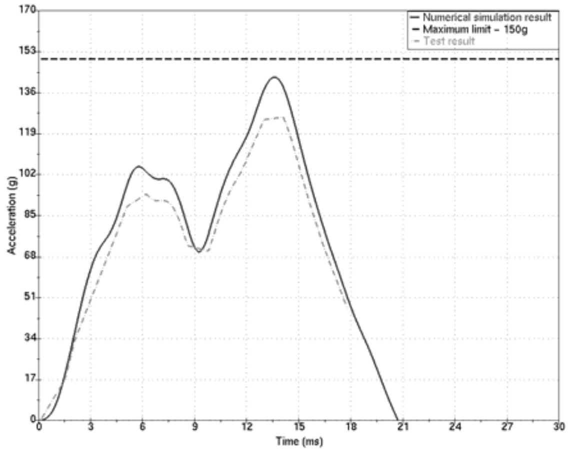

Fig. 6 Acceleration of the legform

The values obtained for the other two criteria (maximum displacement and dynamic bending) are also under the regulation limits (Figs. 7 and 8)

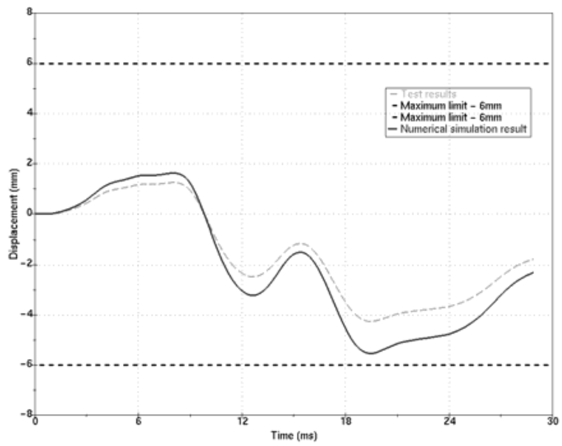

Fig. 7 Max displacement of the legform

According to the numerical simulation, the part requirements are now validated. Then, at the end of the project a physical test will have to be done with the following two objectives:

-to validate physically the characteristics of the parts;

-to obtain data measurements, which will help to better correlate in the future the physical phenomena with the numerical simulations.

5.3. Correlation with tests results

During the final period of the project, a physical test has been done. This test confirmed what we already knew from the numerical simulations, that the front part of the car respects pedestrian crash criteria.

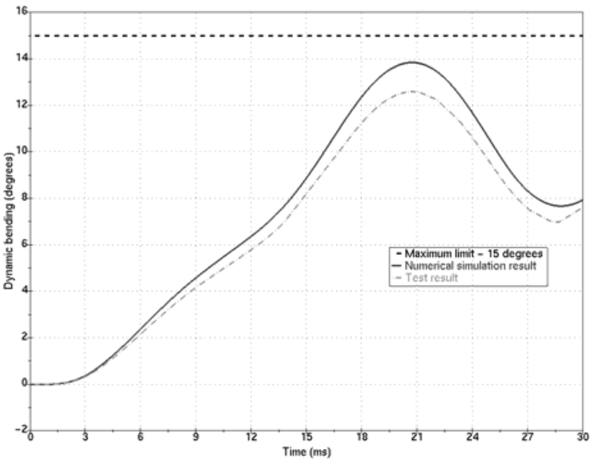

Fig. 8 Dynamic loading of the legform

After obtaining the test results, a correlation with the numerical simulation is done. Generally, is has been observed that we can predict the results with an accuracy of up to 90%.

An important fact to notice is that the numerical simulation results always overestimate the values obtained in the tests results. In this way , we are sure that in the worst case possible the pedestrian crash criteria will not be surpassed.

7. CONCLUSIONS

Even if respecting the pedestrian crash criteria is a very challenging task today, it is known that in the near future it will be even more difficult, as the severity of criteria will increase in the following years.

The key to improve the pedestrian crash performance with a well-balanced proportion between cost and time remains the numerical simulation.

Today, the differences between the test results and the numerical simulations are in an acceptable limit, nevertheless we hope that in the near future to arrive at a even better degree of correlation. This will allow us to save money on intermediary tests and save important time on a highly competitive market.

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