Studies about the Behavior of the Crash Boxes of a Car Body

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Abstract. A continuous evolution of requirements and standards sheds over the development of new vehicles (for example EuroNCAP ratings) in order to create competition between same market models customer related. The low speed impact protection has to be permanently improved as the damage of the front end structure of the vehicle to be reduced to minimal. As a consequence, a lower damage implies less repair costs and therefore a lower insurance category. The front end structure, including the bumper, responds for the absorption of the kinetic energy created during the impact with maximum efficiency in order to avoid the large deformation of structural components. This is only one of the constraints that the front end structure has to cope with, additionally we can mention the dimensioning of the front end of the vehicle which can affect the packaging, which is mainly influenced by the design, styling and the pedestrian requirements intended to be accomplished by the vehicle. The present paper focuses on the low speed urban impact, offering an overview over the actual state, the load configuration, the applicable regulation, the challenging requirements of a modern front structure, which the modern bumper has to comply with and the finite element simulation of this kind of test.

1. Introduction

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

The numerical simulation has gained more and more terrain facing the need of cost efficiency and rapidity of the project development. After the manufacturing, a car has to pass in the first place the requirements of the homologation agencies and secondly, 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.

Using virtual prototyping and numerical simulation, we can improve the performance and the cost of the part before is it actually built. In addition to the numerical test, a physical one is carried out in order to validate that the part meets the requirements. As a consequence, 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 consists in observing immediately if one part of the assembly does not comply with the specifications, rather than following an expensive testing procedure and waiting between the test and the post-processing of the results. 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 simultaneously while observing in real time the global effects.

If it shows that with the current front bumper design it is impossible to attain the required performances, a geometry change can be proposed [9].

The passive safety load cases can be divided into: high speed crashes for front, side and rear impacts, occupant and pedestrian protection and low speed crashes which are mainly performed for insurance classification purposes. In order to ensure permanent evolution of pedestrian protection requirements significant structural changes of the vehicle front structures are mandatory. All these modifications applied to the front end are in opposition with the performance of the other safety load cases [4]. Therefore, for the automotive engineers it represent a never ending challenge to develop a front end structure that will attend the optimal performance for all the load cases.

The requirements of low speed impacts are imposed by several national and international standards. Some of these are mandatory to be respected in order to homologate the vehicle (CMVSS 215 in US [10] / ECE-R42 in Europe), others to evaluate the insurance level (RCAR).

2. Requirements of modern bumpers

Favorable insurance categories, sufficient deformable zones for pedestrian protection and conflicting low speed legislation aspects require an effective design of bumper systems. The modern bumper system has the function of absorbing the energy of the low speed impact, thus avoiding higher vehicle damage. The energy absorption capacity of the bumper system during a crash is evaluated by the load-displacement response. The area under the load-displacement curve is a measure of the energy absorbed. During a low speed impact, the bumper system has the function of preventing damage to the body in white. Hence, the maximum impact load transmitted through the system has to be limited. The maximal displacement is specified by the vehicle design. The ideal bumper system has a load-displacement response which acts as a step function. The load rapidly reaches the maximum value and remains there throughout the crash.

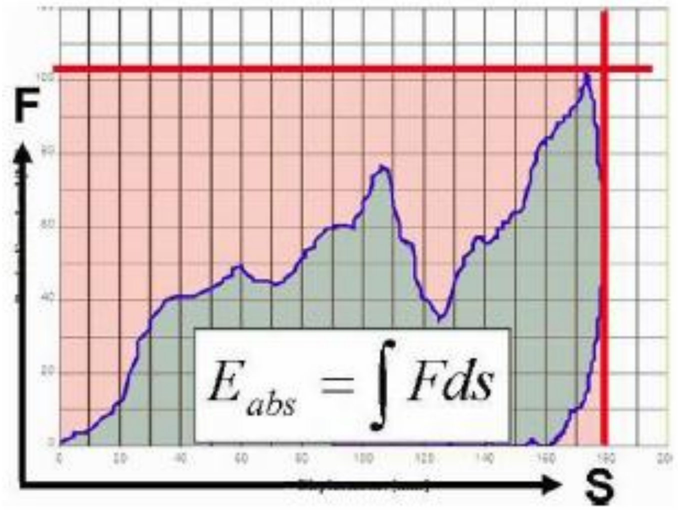

Figure 1. Example of force-displacement curve [8]

The modern screwed bumper systems are composed of a bumper beam and two energy absorbers (e.g. crash box). The old bumper systems were welded to the BIW instead of being screwed. The picture below shows the differences between the two solutions. The advantage of the modern bumper system is the possibility of replacing each part individually in the event of a damage without to pass in the process of cutting and welding. The energy absorbing crash box is placed between the bumper beam and the front rail of the vehicle structure. The crash box has to crush in a specific way, so that the forces and bending moments transmitted to the front rail are limited and the rail does not undergo any significant plastic deformation. As a result the rail does not need to be replaced. In parallel, bot cosmetic damage (e.g. fenders, headlamps, bonnet, etc.) and the damage to the expensive mechanical parts (e.g. radiator, condenser, engine bay components, etc.) have to be kept to the lowest possible [2],[3].

New bumper systems have some disadvantages also: for example, not only does the production complexity increase, but also the cost, weight and vehicle front console. This dimension is caused by the increased distance between the bumper beam and the engine bay components (in order to avoid damage). Additionally, the implementation of deformation elements in the front bumper beam increases the required space for packaging. A third factor responsible for the large front console of the vehicle is the necessary space between the rail and the bumper fascia. Accomplishing the optimal energy management is hard, despite the desire of having a compact front end, required by regular styling reasons [6].

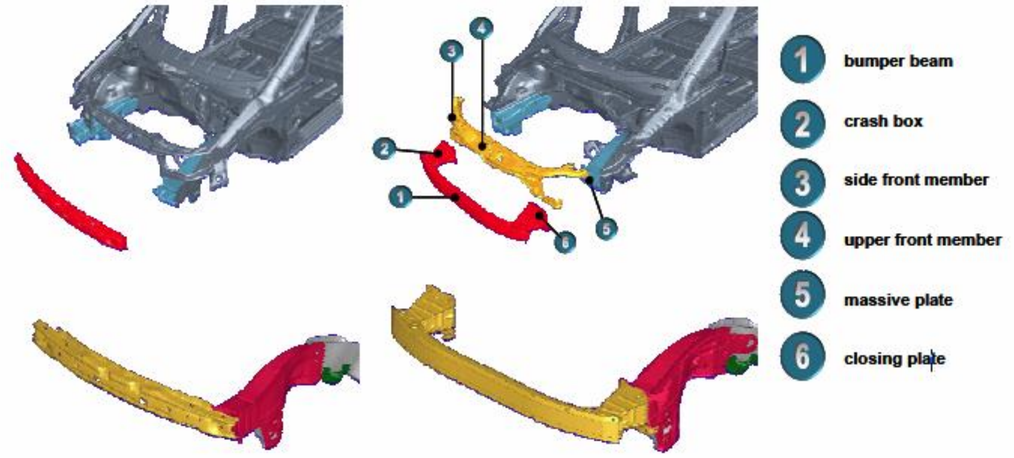

Figure 2. Front end vehicle structure - old/new [8]

As mentioned above, low speed impacts are regulated by an amount of different legal requirements and insurance classification test. It is a challenge to design the most efficient bumper system for all existing load cases simultaneously, because the requirements are in some cases at opposite sides, for example between Europe and North America. While the bumper beam and the crash box should be designed stiff in order to pass the pendulum tests for North American market, the crash box has to be able to crush in the Danner test, without any plastic deformation of the front rail. To solve this problem one alternative used by the global manufacturers is to have different designs and systems for both North American markets and European markets.

Structural changes to the vehicle front end structure to achieve pedestrian protection demands can affect adversely the low speed performance. In order to ensure the required protection for pedestrians, the vehicle must absorb the impact energy by means of a deformable soft structure which has sufficient deformation space. For lower leg protection, an optimized low-density foam in front of the bumper cross member can be integrated. This foam reduces the efficiency of low speed bumper system, so that the barrier intrusion is higher. Hence, without further measures, the vehicle damage and the repair costs would increase, which would intensify the insurance classification.

An effective design of the bumper system must also fulfill certain requirements regarding high speed crashes. During a high speed impact, the crash box has to crush first and the front rail should be able to absorb most of the deformation energy. Due to RCAR test, the crash box is not calibrated in this manner and cannot be efficiently used for high speed crash.

3. Low speed finite element simulation

For researching the low speed impact it was used a finite element model compiled with the explicit solver PAM-CRASH, well known as one the reference software of the automotive industry. This model is composed of a simple front beam made from steel with a thickness of 1mm. The interface with the rails of the vehicle structure is chosen to be as the latest solution used, with two crash boxes which have the same characteristics as the front beam. The two crash box elements were designed in several simulations as front rails especially to observe the contrast between the two types of technical solutions and to evaluate the performances.

The striker used is the same as the one described in the Regulation [1], presented also below in the study. It's considered a rigid body [5], guided along the X axis of the vehicle, with a speed of 4km/h and laden with a mass of 1500kg (which can be approximately the mass of a modern vehicle). At the level of the crash boxes there were added TIED contacts in order to define the interface with the crossbeam. At the level of the rail, the crash boxes are considered blocked on all directions, as a hypothesis that deformation may not affect the front structure. The simulation was conducted in three positions: centered, offset and corner.

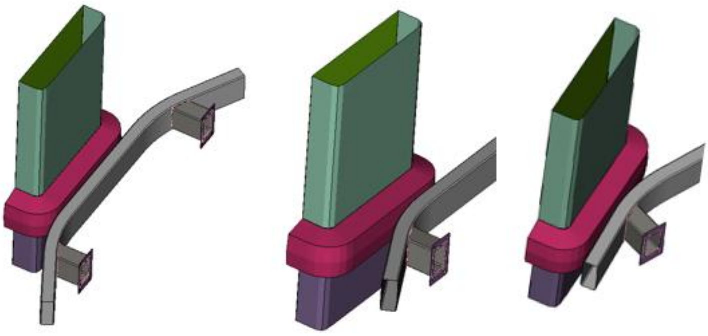

Figure 3. Finite element model – initial condition

The configurations used in the simulations are described in the list below:

1. Classic front end – centered impact
2. Classic front end – offset impact
3. Classic front end – corner impact
4. Modern front end – offset impact / crash box type 1
5. Modern front end – corner impact / crash box type 2
6. Modern front end – centered impact with pedestrian absorber [7]

Below, the results of these simulations will be briefly analysed. It was chosen as a hypothesis a maximum limit of 5% for plastic deformations. (We can consider that above this limit the plastic deformation it becomes visible on the physical parts)

For the 1st impact configuration, we can observe in the figure below that the front beam was deformed well above the limits and we can conclude that the damage cannot be repaired.

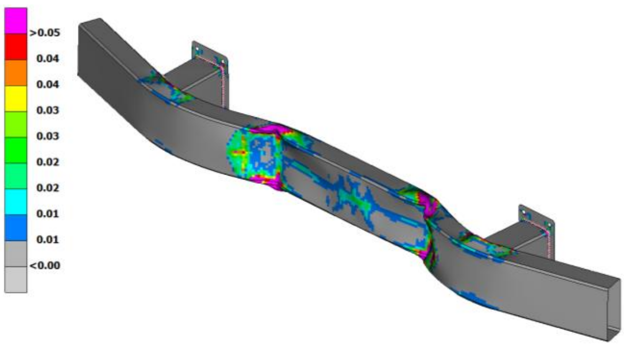

Figure 4. Classic front end – centred impact

The rails, as it were designed in this simulation, were not affected by the impact, so we can conclude that is necessary to design a front absorber in order to reduce the plastic deformation of the crossbeam.

Similar results can be seen in the 2^{nd} and 3^{rd} configuration, the load case being in the offset/corner position. In this case, as clearly appears it's mandatory to develop a crash box structure.

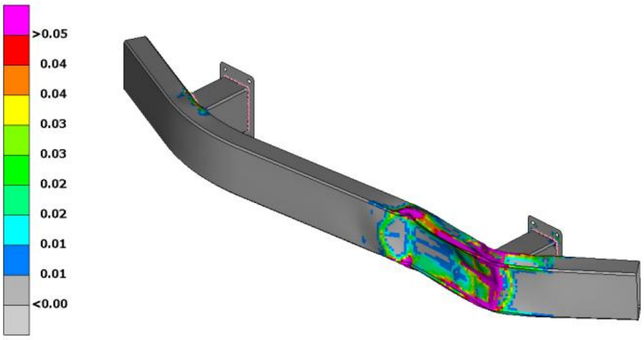

Figure 5. Classic front end – offset impact

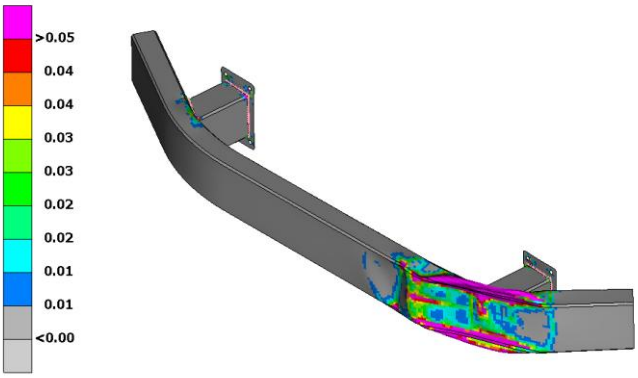

Figure 6. Classic front end – corner impact

The behavior of the crash box was evaluated in two manners described below. In the first it were made cuttings on the part in order to start the deformation. In the second solution, the geometry of the part was reconstructed and also the thicknesses were updated. Many types of technical solutions that are already patented can be applied in order to have the same result. Current trends in bumper design find this kind of part added by the manufacturer in standard equipment of the vehicle [6].

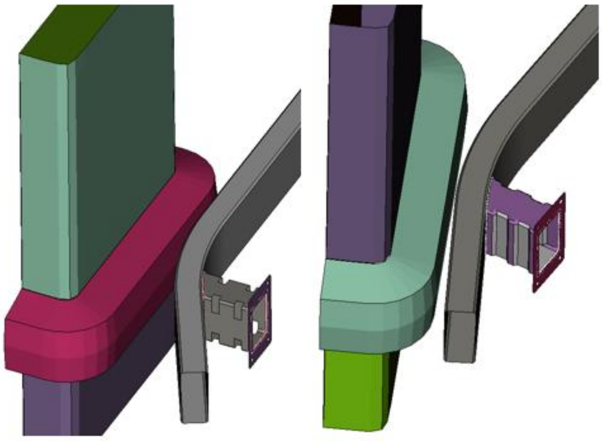

Figure 7. Crash box definition used in simulation

The results obtained are better than the ones of the classic solution, but the plastic deformation still exceeds the requirements imposed.

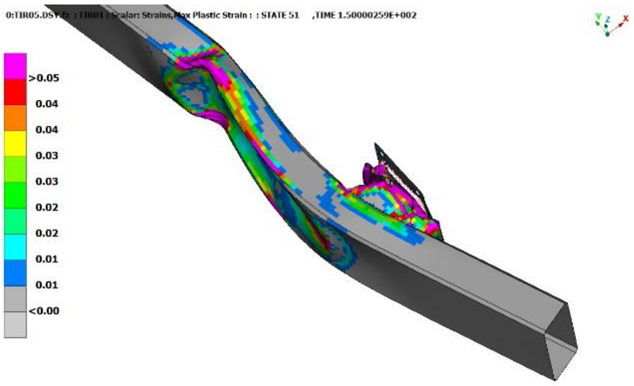

Figure 8. Modern front end – offset impact / crash box 1

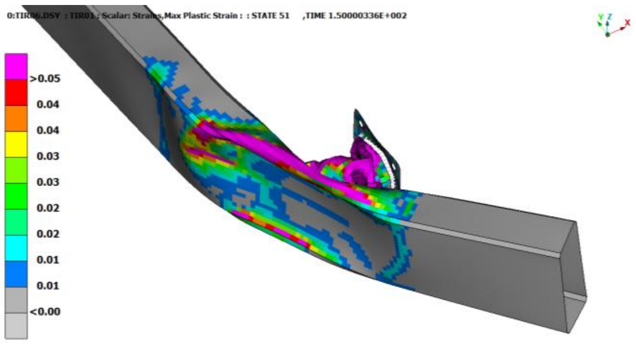

Figure 9. Modern front end – corner impact / crash box 2

In the last case it was designed a pedestrian type of absorber in front of the crossbeam. The material used it was a specific one for this type of application, a PP/PE thermoplastic. The absorber is 100mm long in X axis, with the exterior thickness of 3mm and interior rib thickness of 2.5mm. Additionally, in the centre section it was added a crossbeam support that in modern BIW is welded between the crossbeam and the front end cover, because of the lack of rigidity detected in previous simulation.

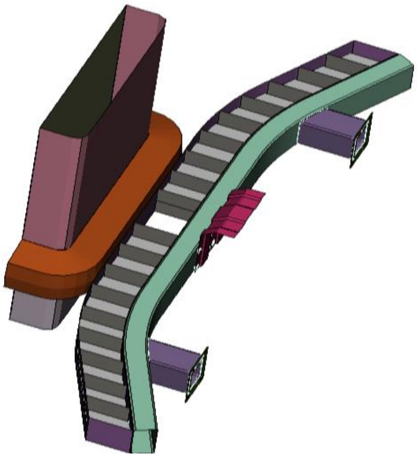

Figure 10. Modern front end – centered impact with pedestrian absorber

In this case it can be seen in the figure below that the energy absorption is made by the front absorber. The deformations at the level of the crossbeam are almost not visible.

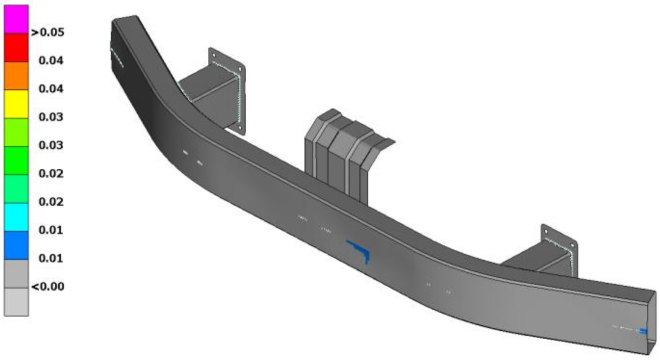

Figure 11. Modern front end – centered impact with pedestrian absorber (front beam plastic deformation)

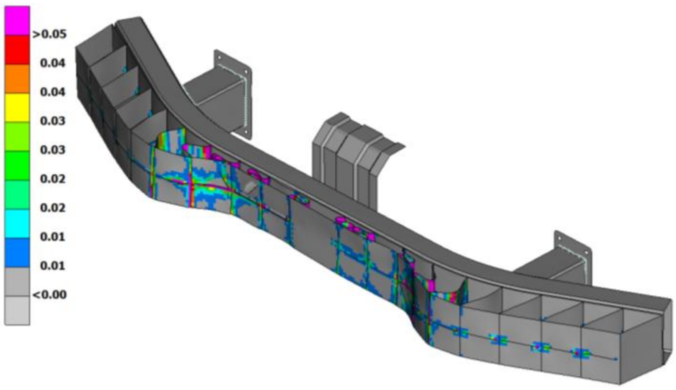

Figure 12. Modern front end – centered impact with pedestrian absorber (front absorber plastic deformation)

Furthermore it was conducted a curve analysis of the contact force for all the simulations launched.

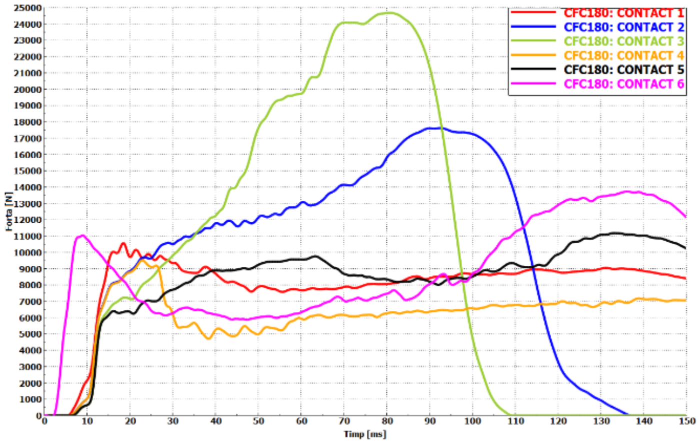

Figure 13. Contact force curves

It is visible that the characteristics are almost the same for the models 1, 4, 5 and 6, the energy absorption being made properly, but in different manners and by different parts. The curves 2 and 3 show that the two crash box that were considered as front rails, were implying the proper manner of absorption, giving a high peak and physically a large deformation of the crossbeam.

This fact can be explained by the internal energy of the each crossbeam during each impact. The first three curves (red, blue and green) show that the part is strongly deformed. The next two curves (black and orange) show that the stresses at the level of the beam were reduced. The final model that represents the modern solution of front end system shows a little influence over the crossbeam, concluding that only the plastic parts were to be damaged, and the cost of the repair being in this case minimal.

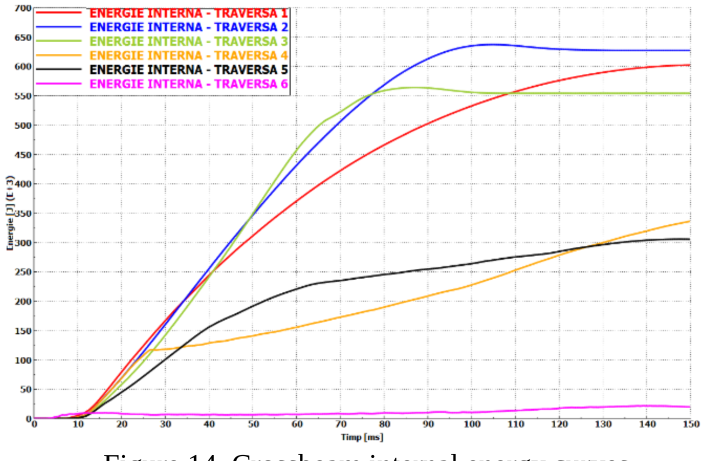

Figure 14. Crossbeam internal energy curves

4. Conclusion

The different low speed urban impact legislations and insurance tests represent a recently and strongly demanding challenge for the automotive industry, and it's known that in the near future it will be more difficult as the severity criteria will increase.

By adding a crash box on each front rail and a plastic or foam absorber on the front cross member it can be reached a compromise in order to comply with low speed impact, high speed impact and pedestrian impact requirements. The level of force transmitted to the front structure can be reduced by approximately 3 times in the case of the vehicle equipped with the parts mentioned earlier. Also, in the majority of the load cases, the worst case scenario is that the front bumper fascia and the front absorber might be replaced. (in typical impact the plastic deformations cannot be observed)

It's mandatory an optimization to be conducted related to front end structure in order to assure all the load cases and styling visions.

The key factor towards to improvement of the front end structure systems performance remains the numerical simulation in upstream phase of the project.

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