VEHICLE ARCHITECTURE DIMENSIONING FOR PEDESTRIAN PROTECTION USING FINITE ELEMENT ANALYSIS

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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. Pedestrian impact protection has to be permanently improved as the damage to front end structure of the vehicle to be reduced to a minimum.

The front-end structure, responds for the absorption of the kinetic energy of the impact with maximum efficiency in order to avoid the large deformation of structural components and good behavior during a pedestrian impact. 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 architecture, 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 architecture sizing of the vehicle front end using the finite element analysis, by a parametric model that can approximate the geometry, stiffness and an overall performance of the configuration tested. The main benefit of this tool is the minimal calculation time spent in order to have fast results of a design geometry proposal, a key factor in the convergence between engineering and styling trends, especially in the prototype phase (both numerical and physical) of all contemporary vehicles.

Keywords: pedestrian protection, vehicle architecture, finite element analysis

1. Introduction

The European Union has had impressive success in achieving the highest pedestrian protection level on the globe. In 2013, 5.712 pedestrians were killed in road accidents in the EU, which is 22% of all fatalities. In the last decade, in the European Union, pedestrian fatalities were reduced by 37%, while the total number of fatalities were also reduced by almost 45%.

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The present paper focuses on calibration of a simplified model that can be further configured in a parametric manner for future analysis. The full-scale model will be briefly detailed and the short correlation with both the simplified model and physical test results will be analyzed. The configuration of the simplified model and the influence of each parameter will be analyzed in detail and the novelty and the utility of this tool will be highlighted in the final chapter.

2. Pedestrian lower leg finite element analysis

A full-scale model (figure 1) has been developed starting from a CAD geometry for a pedestrian impact finite element analysis simulation. The model consists of the following parts: body in white monocoque structure, four cross members (superior and inferior), two spring arches, superior crossbeam, test wertra main crossbeam with two crash boxes, front technical support, bonnet, two fenders, two headlights, front bumper and a foam type absorber. The model has been section cut starting from A-pillar in order to reduce the calculation time. The impactor used for this test is similar to the EEVC (TRL) specifications [11], in terms of dimensions, material types and deceleration measurement principle. The analysis was completed with the help of PamCrash solver and during the research there were also used references, manuals and model specifications from LS-Dyna software.

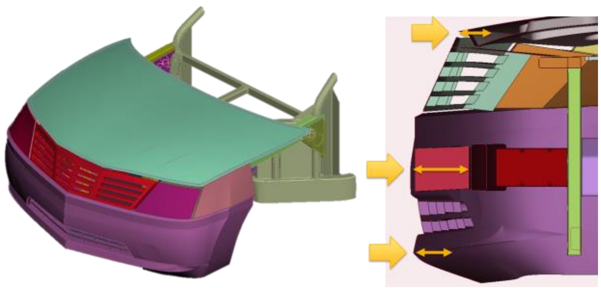

Fig. 1. Pedestrian full scale model overview and section

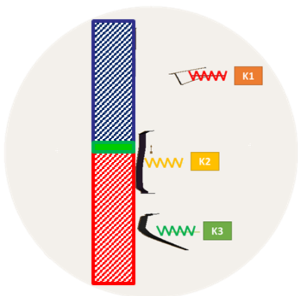

Fig. 2. Pedestrian simplified model

Starting from the full-scale finite element model, a simplified model (figure 2) was developed by isolating only the three sections of impact: lower bumper section, central bumper section and bonnet leading edge section. Each section will have assigned a spring type element which will be defined to reproduce its local stiffness. The contact forces between the impactor and the front bumper, between the impactor and bonnet, and the displacements for the three impacted sections were extracted from the full-scale simulation results (figure 3).

The data obtained was used in the simplified model for calibration of spring constant (K1, K2, K3 – figure 4), by defining load-displacement curves for each impact section.

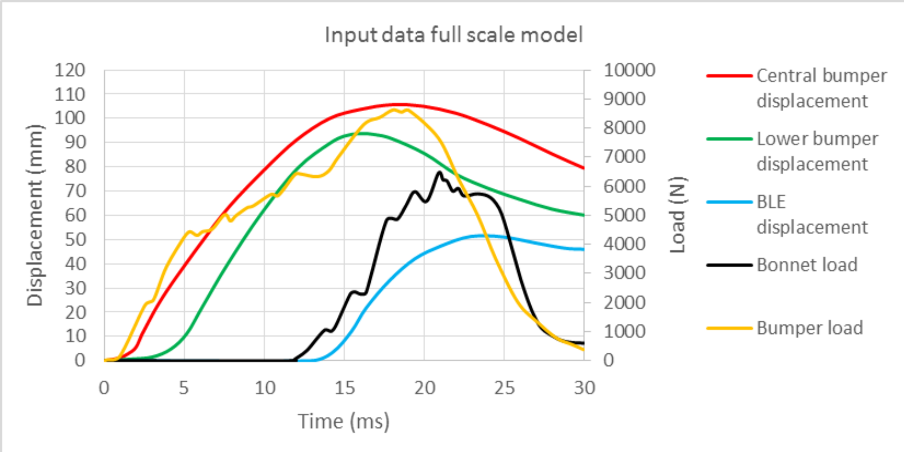

Fig. 3. Contact forces between bumper and bonnet versus lowerleg impactor, displacements of bumper and bonnet – data from full scale model for input in simplified model

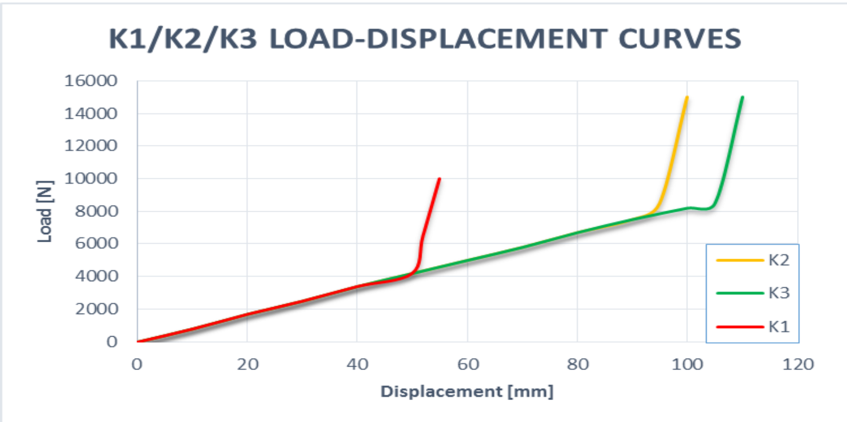

Fig. 4. Bonnet and bumper load-displacement curves used in simplified model

In order to validate the accuracy of the simulation results, a physical test was launched in an appropriate impact configuration (figure 5). A Renault Clio vehicle, with modifications conducted to the front bumper and front cross member in order to accommodate an EPP absorber specification, was used as test stand.

The impactor used was developed in the same way as described by the specifications in Regulation EC631/2009 [11], consisting of two circular cross sections (bars) of Ø70mm in diameter and 500mm in length, a simplified rotational knee joint at the intersection of the two segments, three 15mm thick foam layers made of 80% NBR (rubber butadiene rubber) and 20% PVC (polyvinyl chloride) and an exterior layer 1.5mm thick made of self-adhesive neoprene.

The impactor was equipped with an X200-4 accelerometer [18], produced by Gulf Coast Data Concepts, with 3-axis measurement capabilities and ± 200g range, which can be used with a sampling rate of up to 3200Hz.

The boundary conditions proposed for the physical impact test were different from those specified in actual regulations. In the absence of a pneumatic system that launches the impactor in vehicle direction, it was chosen the reverted condition, the impactor being aimed by the vehicle. This configuration is closer to real accident conditions, but also has a number of limitations that need to be closely monitored during the tests in order to validate the results.

The surface, on which the car is running during the tests, shall be approximately flat, without unevenness, and the vehicle speed shall be measured and stabilized at least 3 seconds before the impact is produced. It has been chosen for instantaneous speed readings, vehicle OBD data, being one of the most accurate and simple measurement methods.

The impactor must be positioned appropriately (the accelerometer positioning in the direction of impact can be tracked as a reference) and must not be affected by any external environmental factors. The ambient temperature should be within the range of 23°C, ±3°C.

Impact kinematics were captured on digital support at a rate of 240 frames per second, similar as principle to the one used in the EuroNCAP impact tests.

Fig. 5. Pedestrian physical test configuration

The correlation results (figure 6) show high accuracy between the two simulation models and the physical test. The CFC filtered curves of lower leg deceleration analysis show that the peak values are very close. If all the structural and styling parameters of the vehicle are available, the reduced scale model can be defined and modified quickly, and it can estimate with good accuracy the behavior of the testing configuration.

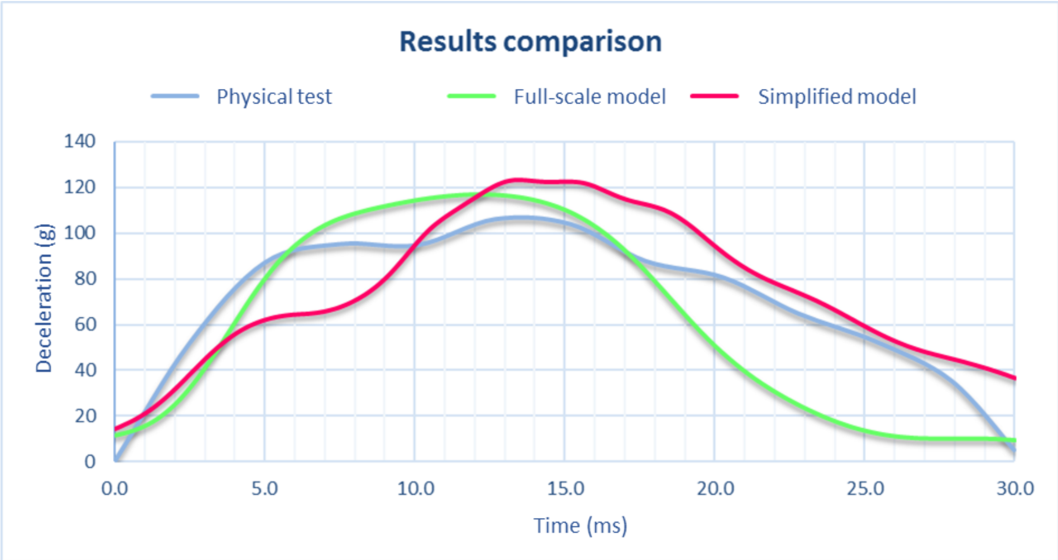

Fig. 6. Correlation of physical test (blue), full scale model (green) and simplified model (red)

3. Parametric lower leg finite element analysis model

Following the correlation result described above, a parametric model (figure 7) has been set up, taking into account main architecture constraints (styling and structural main factors).

X1	Grill and hood deformation depth
X2	Energy absorber & beam packaging space X
X3	Lower bumper skin deformation depth
X4	Middle structure - BLE X distance
X5	Middle structure - lower section X distance
Z1	Hood height section
Z2	Energy absorber & beam packaging space Z
Z3	Lower bumper skin / beam (opt) section
Z4	Impactor height Z (vs. absorber)
Z5	Middle structure - BLE Z distance
Z6	Middle structure - lower section Z distance
Z7	Lower structure - ground distance
Z8	Impactor ground distance (optional)

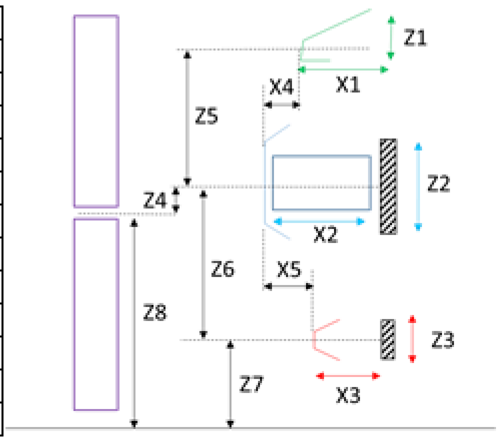

Fig. 7. Parametric model description

In order to see the influence of the parameters, 32 sample iterations have been launched and the most important results can be identified in table 1.

For displacements influence analysis, two simulations with a range of ±10mm were launched for each parameter and for spring scale factors, the values considered were 0.8 and 1.2, as for a 20% variation. The color code used consists of red background for increasing value, yellow background for equal or close value and green for decreasing value. All the deceleration results are compared with the reference value of the parametric sample model (111.4 g).

As it can be observed from the results values in table 1, the variation of spring scale factor K1 shows that for the bonnet leading edge section, if the stiffness is decreased, the deceleration value slightly decreases. The main influence of a parameter over the results can be identified for the energy absorber stiffness (variable K2) that shows a high gain in deceleration value. This means the energy absorber that was used in the full-scale simulation is stiffer than it is normally necessary for pedestrian impact and it can be further optimized. The K3 parameter variation shows increasing values for both cases. In this specific case of the leg catcher area, the calibration is normally done after the main absorber dimension is established. It can be observed that a decreasing value of the parameter is producing a high influence over the results, meaning that the absorber is reaching its compression limits, while the lower area lacks in stiffness.

Table 1.

Influence of parameters over the reduced scale model results

Parameter	Factor	Deceleration (g)
Reference values		111.4
K1	⇑ +20%	112.0
	⇓ -20%	111.2
K2	⇑ +20%	125.3
	⇓ -20%	103.6
K3	⇑ +20%	114.5
	⇓ -20%	119.5
X4	⇑ +10mm	112.8
	⇓ -10mm	110.6
X5	⇑ +10mm	113.8
	⇓ -10mm	112.9
X4 X5	⇑ +10mm	135.9
	⇓ -10mm	112.3
Z4	⇑ +10mm	110.1
	⇓ -10mm	111.7
Z5	⇑ +10mm	111.3
	⇓ -10mm	112.3
Z6	⇑ +10mm	112.2
	⇓ -10mm	110.5
Z7	⇑ +10mm	111.5
	⇓ -10mm	110.7

The X4 parameter, corresponding to the gap between the bumper and the bonnet leading edge, shows that for gap reducing, the influence over the result is positive. The more advanced the hood is to the bumper, the more impact energy it absorbs and the decelerations are reduced. The X5 parameter, the gap between the lower bumper section (leg catcher area) and the central bumper section, show value increasing, similar to corresponding K3 parameter. If both parameters X4 and X5 are increased, it can be observed a high impact over the results of approximately 20g. This impact configuration is not recommended.

The Z1, Z2 and Z3 parameter variation shows that for a higher volume available, in most cases, the deceleration value is lower. Z4 parameter variation is specific for each case defining the energy absorbing strategy for leg catcher and bonnet leading edge areas. If the Z4 parameter is above the rotational joint of the knee impactor, the K3 and X3 parameters must be increased and X5 parameter must be reduced. If the variation is in the other direction, the modifications must be conducted in the same manner to X1, K1 and X4 parameters. The Z5 parameter shows that the variation is negative in lower bonnet cases. In the opposite manner, for Z6 parameter, in cases of high leg catcher areas, the value increases.

The Z6 parameter, the ground clearance of the impactor related to the vehicle, is one of the most important factors that influence all other parameters and the accuracy of the results. Z6 parameter is the first one that has to be set.

In a similar manner, all parameters can be judged in order to determine if the unique tested configuration might comply with pedestrian protection testing procedures.

4. Conclusions

The actual trends in automotive design and packaging are to reduce the front-end area of the vehicle. This fact generates big constraints from architecture point of view, meaning that with less available volume, a higher amount of impact energy must be absorbed. In order to accelerate the process of downsizing, finite element analysis predictive simulations must be used, to have an overview over the results, which must comply with continuous evolving requirements of the regulations all over the world.

Using the described approach in packaging downsizing by using finite element analysis, many advantages can be gained, fast calculation time and less pre-processing time with optimal accuracy rate, quick overview over the design constraints and solutions, evaluation of many geometries simultaneously, in this manner defining a solid starting point for the energy absorbing strategy.

Future work can be extended to other pedestrian load cases.

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