Development of Pedestrian Protection for the Qoros 3 Sedan

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Abstract

Pedestrian protection has become an important part of the Euro NCAP consumer test and to achieve a 5-star rating for crash safety, a good rating for the different pedestrian load cases is imperative. It was decided at the very start of the Qoros 3 Sedan's development program that this should be made a priority. A skilled team of safety engineers defined the layout of the vehicle to support this target, and an extensive simulation program using LS-DYNA® was planned to define and validate the design intent without compromising the design of the vehicle as well as maintaining all other important vehicle functions.

This paper will provide an insight into part of the journey taken to establish a new vehicle brand in China, fulfilling high European safety standards at an affordable cost, and how Qoros succeeded in this mission with a combination of skills, extensive CAE analysis and finally the validation of the recipe during physical testing. The paper will highlight how the high rating for pedestrian protection was obtained and give a short overview of the complete safety development of the Qoros 3 Sedan.

Introduction

This paper introduces Qoros and the development of the first vehicle on Qoros' new compact-segment platform, the Qoros 3 Sedan. It is difficult to present a whole vehicle development in one paper so this text focuses on pedestrian protection as the main topic and will discuss how the rating for pedestrian protection was obtained in the Euro NCAP test as well as discussing some areas where difficulties were encountered with the initial assessment using CAE.

Establishing Qoros, a New Automotive Brand

Qoros Automotive Co. Ltd. was founded in 2007 with the principal aim of developing vehicles that are differentiated in their design, safety, and connected services and that exhibit international standards of quality.

The company is headquartered in China, with its operational center in Shanghai, supplemented by offices in Munich, Germany and Graz, Austria. An all- new Qoros production facility has been built in Changshu, a region of high importance for China's rapidly growing automobile industry.

In the growing Chinese automobile market, Qoros has an exceptional position, with a brand identity and product positioning that is clearly distinguishable from domestic car manufacturers and international joint ventures.

Sales of the company's first production model, the Qoros 3 Sedan, started in the fourth quarter of 2013. Qoros plans to rapidly expand its model family to meet the needs of different consumer groups.

Platform Development

The Qoros 3 Sedan is the first vehicle developed on the CF1x platform. The platform development program was undertaken in parallel to the development of the first vehicle and will form the base for a series of vehicles from Qoros. In March 2014, the second vehicle on the platform, the Qoros 3 Hatch, was revealed at the Geneva Motor Show. Both vehicles share the same front structure and design so both will have the same performance with respect to pedestrian protection. The foundation for the development of the platform was to establish a new vehicle with high safety standards and high quality, but using cost effective solutions.

Figure 1: Qoros 3 Sedan

The development of the Qoros 3 Sedan relied heavily on simulation during the concept selection phase, serial development as well as during the production optimization phase after the first test results.

Target and Initial Package/Layout Definition during Concept Phase

With the Qoros 3 Sedan, the development team had the target to achieve a 5-star Euro NCAP rating in the organization's 2013 assessments. But what does it take to be a 5-star vehicle? Euro NCAP's assessment program defines different areas, or boxes as they are called, where the vehicle has to excel, Pedestrian Protection being one of them.

To achieve a 5-star score in the 2013 assessments – the organization's toughest ever – required the vehicle to obtain a minimum of 60% of the 36 points available for each box. Pedestrian protection impact areas are related to the most important body impact areas where fatalities will lead to death or large injuries. Therefore, minimizing the harm to vulnerable road users is the aim of a pedestrian friendly vehicle such as the one Qoros set out to bring to market.

While a minimum of 21.6 points was needed for the Pedestrian Protection box, Qoros set itself an internal target of ≥ 23 points. To this was added a 10% margin to cover the variability of the tests and keep a margin of error available and still reach the overall target score. Therefore, the following were the targets for each load case:

Table 1 Target for Head Forms:

HIC	Color code			HIC
		GOOD	<	585
585	≤	ADEQUATE	<	900
900	≤	MARGINAL	<	1215
1215	≤	WEAK	<	1530
1530	≤	POOR		

Table 2 Upper leg limits:

	GOOD	≤	MARGINAL	≤	POOR
Bending Moments [Nm]		270		324	
Sum of Forces [kN]		4.5		5.4	

Table 3 Lower leg limits:

	GOOD	≤	MARGINAL	≤	POOR
Tibia Acceleration [g]		135		180	
Knee Shear Displacement [mm]		5.4		6.3	
Knee Bending Angle [deg]		13.5		18	

The starting point in cascading the targets to each load case was to consider the type of car being developed, C-Class (compact segment), because this is a significant determinant of where the impact lines will be located and thus where the opportunities exist to achieve the score.

The primary strategy was to have intelligent packaging and clever designs, eliminating the need for active systems such as pop-up bonnets or pedestrian airbags: these were ruled out from the beginning of the project. Furthermore, the engine sizes to be used allowed the team to specify a minimum clearance to avoid secondary contacts between the hood and hard components underneath.

Considering the points mentioned above, the targets for each load case were defined as follows:

- Adult Head: 5.5 points out of 10.62

  Almost 45% of the total head impacts were located on the adult head area.

  23% of adult head impacts were directly RED because of being located on the A-Pillar or nearby. The objective was therefore to achieve high scores on the remaining 77% of the defined impact areas.

- Child Head: 9.5 points out of 13.85

  Child head area accounts for 55% of the total head impacts. All of them are located on the hood, which gave the opportunity to achieve a high score by keeping the minimum clearance distance to rigid structures under the hood and having a good design for the inner hood and cowl cover.

- Upper leg form: 2 points out of 6

  A minimum of 2 points was set as a target on the central area. Intensive work was undertaken in conjunction with Qoros' styling team to keep the energy levels below 400 J. Minimum clearance was kept on the central area to allow the front end to absorb the impact energy keeping forces and moments below the thresholds. Hard structures such as the hood closure latch were packaged as far rearward as possible. In parallel, intensive work was undertaken with the headlamp supplier to score additional points for the sides.

- Lower leg form: 6 points out of 6

  Full scores were targeted on this load case. Several iterations of designs were undertaken with the styling team to develop a solution that retained a minimum clearance distance between the bumper skin and the bumper impact beam. In order to have good support from the bottom of the fender (the chin), a lower beam was introduced which also improved the performance on lower speed impacts. A final balance of upper and lower stiffness was needed to reach the target.

Initial Virtual Development

All initial assessments of the pedestrian protection performance were based on LS-DYNA [1] simulations mapping out the head area, upper leg area and lower leg area.

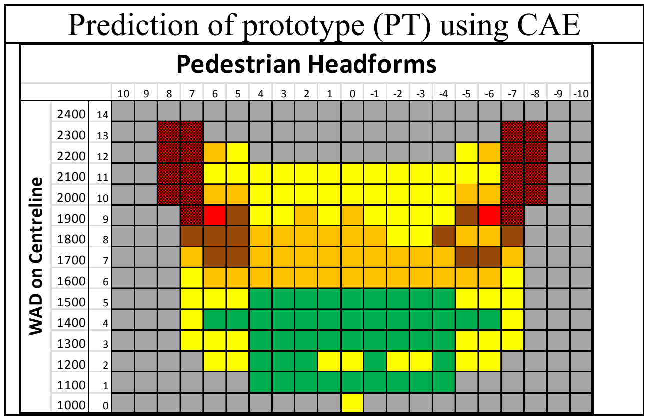


Figure 2 Initial prediction of adult and child impact area

During this part of the project some significant design changes were implemented to support the achievement of the final target of 23 points. For example, the hood latch was repositioned, and the upper longitudinal beam was lowered to allow enough space for the hood to move down. Verification of the collapse of the lower windscreen member during head impact was also done during this phase.

With all these changes incorporated into the design, the predicted results were as shown in Figure 22 above. This resulted in a total of 15.3 points for the head area, 6 points for the lower leg and 2 points for the upper leg, giving an initial estimation of the total score of 23.3 points. As a result, the team was confident when approaching the testing phase.

Physical Testing and Model Verification

When the first prototype was delivered from the prototype build team, the safety development engineers had the first opportunity to correlate the virtual model to the physical test. For head impact, Figure 3 shows the initial CAE assessment compared to the first test results.

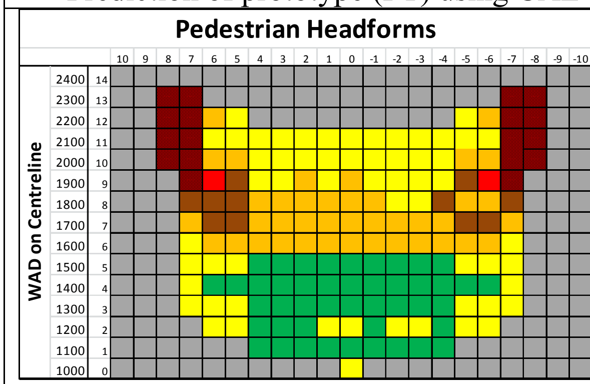
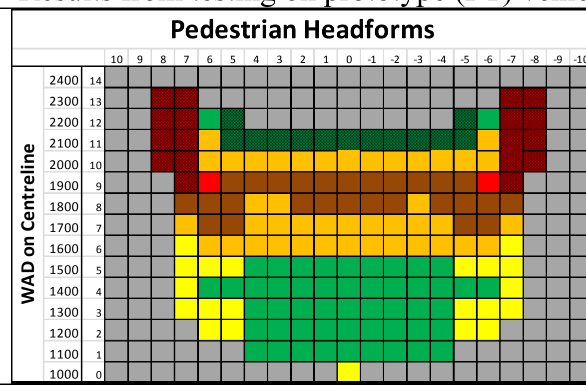
Prediction of prototype (PT) using CAE	Results from testing on prototype (PT) vehicle
	

Figure 3 Comparison between the initial CAE prediction and the first prototype testing

As can be seen from Figure 4, for the majority of the hood for row 0 to row 7, there is a close correlation of the head impacts between the initial CAE prediction and the first mapping of the hood using physical test results.

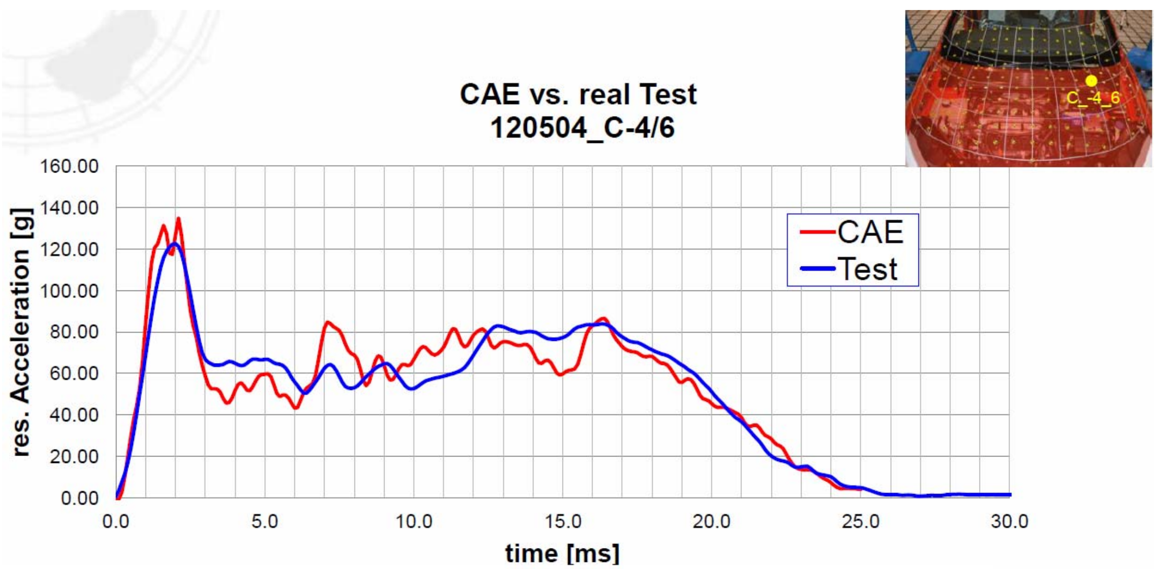


Figure 4 Impact point on upped hood area

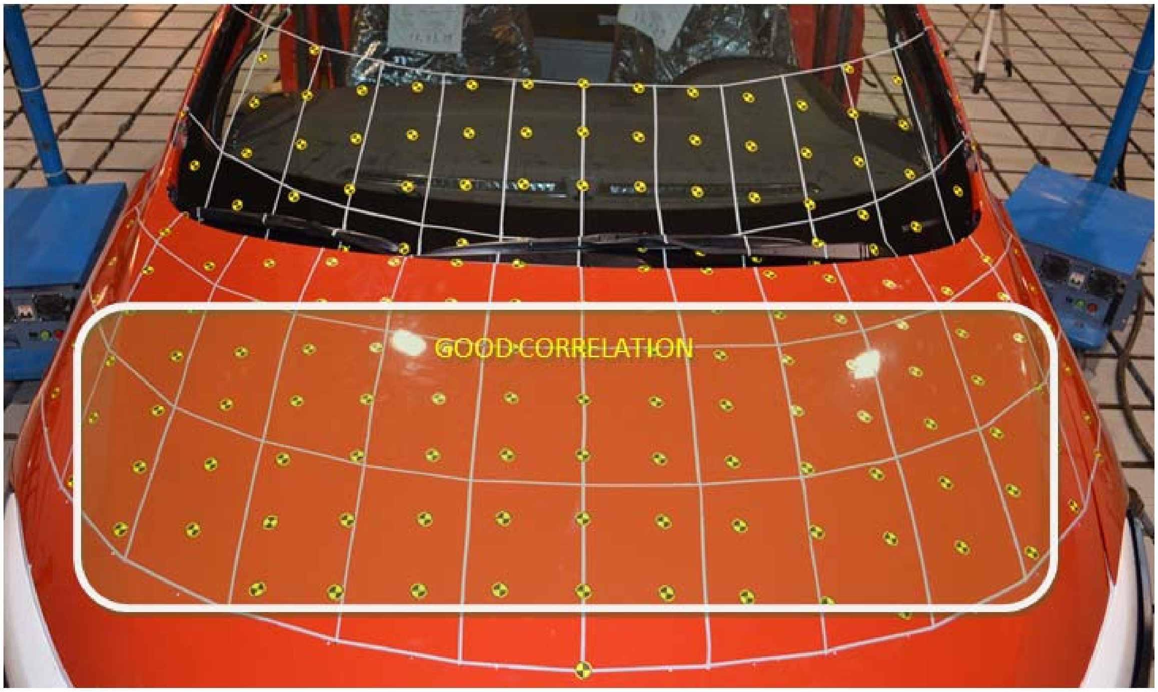


Figure 5 Area indicating good correlation between CAE and Test data

Figure 6 Areas with differences between CAE and Test

However, the initial testing highlighted a poorer correlation in the lower windscreen area. A deeper analysis of this area showed that the main factors for the difference between CAE and physical testing were:

- Missing content in the CAE model used for predicting the results
- Incorrect collapse mechanism for the IP
- Incorrect material data and the geometry of the cowl cover
- Modeling of the physical properties of windscreen.

Missing content in the CAE model

The first test on the lower windscreen area with the Adult Head Form registered a considerably higher HIC value than that predicted by the initial impact simulation in LS-DYNA. After investigation and comparison between the finite element model and the physical car, it was noticed that the sound insulation foam was missing from the area inside the windscreen member and the firewall. This foam significantly stiffened the area behind the windscreen.

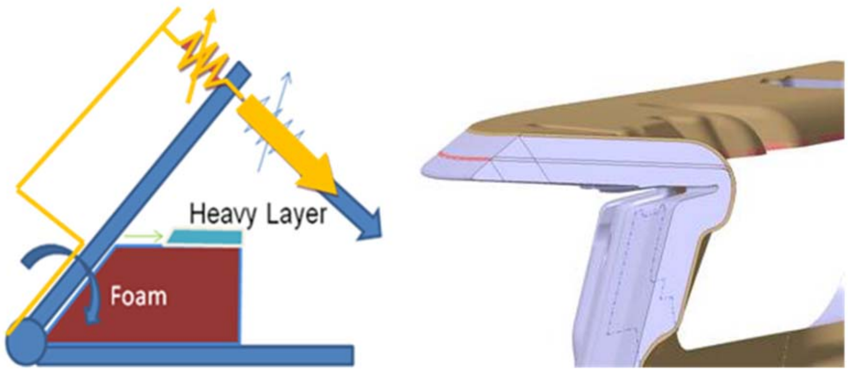


Figure 7 Schematic picture showing the position of the insulation foam behind the glass

This foam had not been part of any of the simulations during the initial development phase and a second test without the foam was undertaken to determine if this was the issue.

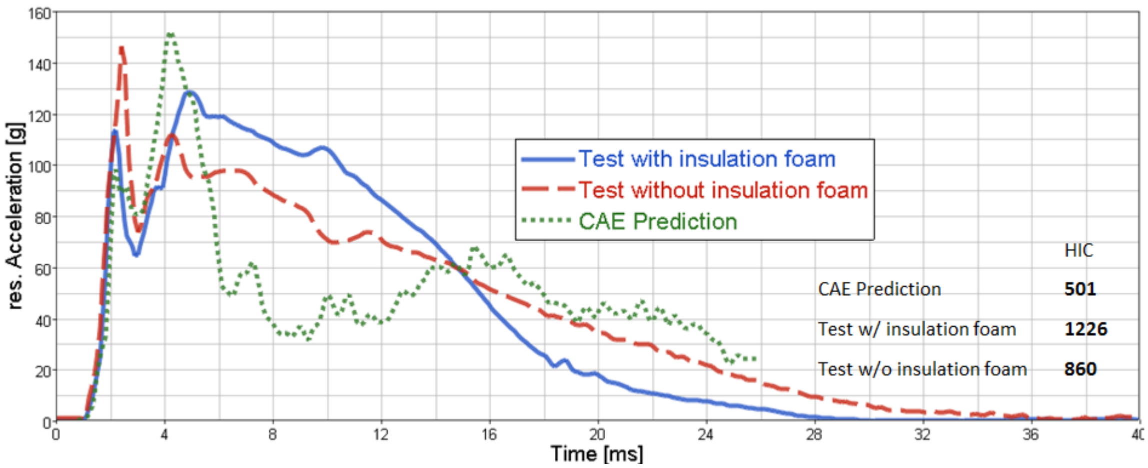


Figure 8 Comparison between predicted CAE and tests for lower windscreen area

Figure 8 shows the result of the two tests with and without insulation foam and the initial prediction using CAE. Even with the foam removed the test still showed a higher HIC value than with the original CAE model. This difference was due to a different collapse mechanism of the IP than the one predicted during the initial CAE development. This will be further discussed in the next paragraph.

To improve the result, changes to the insulation foam in this area were incorporated in the final production vehicle that allowed the lower cross member to collapse freely. This solution fulfilled both safety and NVH requirements.

Incorrect collapse mechanism of the IP

A second area that did not behave like the initial CAE simulation was the collapse mechanism of the instrument panel. This led to further engineering development of the IP. Failure and fracture of plastics are difficult to predict, and in order to improve on the correlation of the instrument panel model, the engineering and safety development teams undertook further component tests that included the IP.

The test setup for these tests is shown in Figure 9.

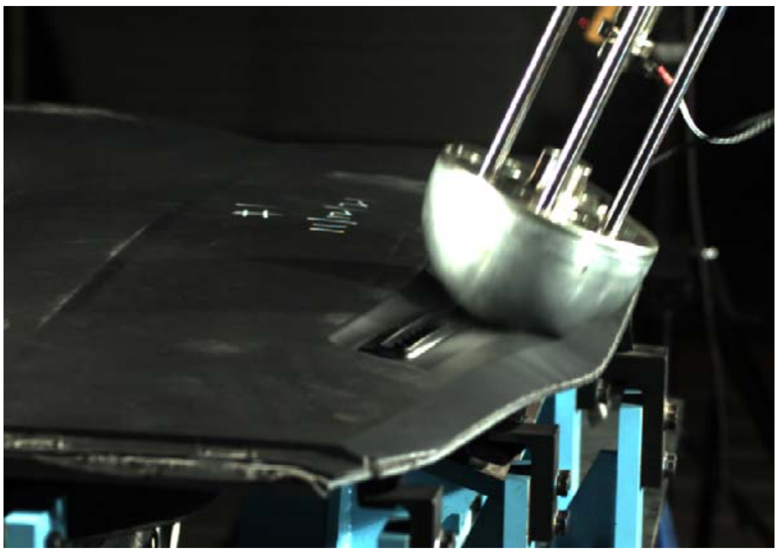


Figure 9 Component test for correlation of IP FEA model

The IP design was improved using a combination of component testing and CAE during an intensive period after the first physical tests and the initial negative test results.

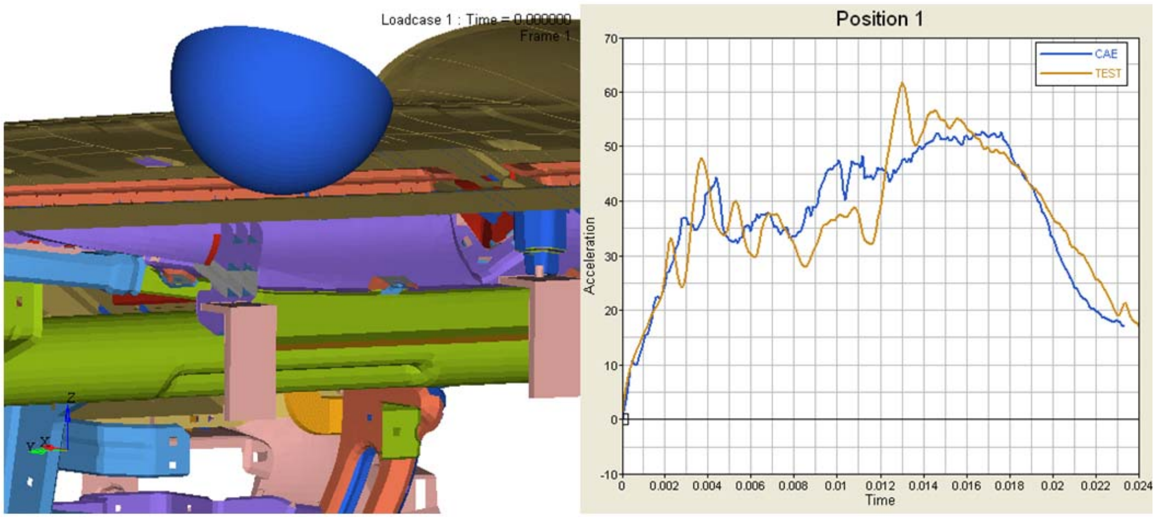


Figure 10 Simulation of correlation test

By improving the IP/Windscreen member area, the vehicle actually gained more points in this area with a relatively small additional allocation of time and resources.

Modification of the material and geometry of the cowl cover

In the cowl area, both the material model and the geometric model of the cowl cover proved to be insufficient to predict the correct score in this area. In general the model showed weaker behavior compared to the test. Once the material model was corrected, further geometric changes to the design of the cowl cover were implemented to improve the score in this area.

Improved modeling of the windscreen

Finally, looking at the test result of a point higher up on the windscreen, point A_-3_9, the initial windscreen model (MAT 24) failed to accurately predict the behavior of the glass. The stiffness of the windshield was too high due the lack of correct cracking behavior. During the final phase of the development program, the windscreen model was improved according to the method described in [2,3]. The analysis shown in Figure 11 and Figure 14 already includes the modifications introduced for both the insulation foam and the improved IP. The final item to correct was the windscreen.

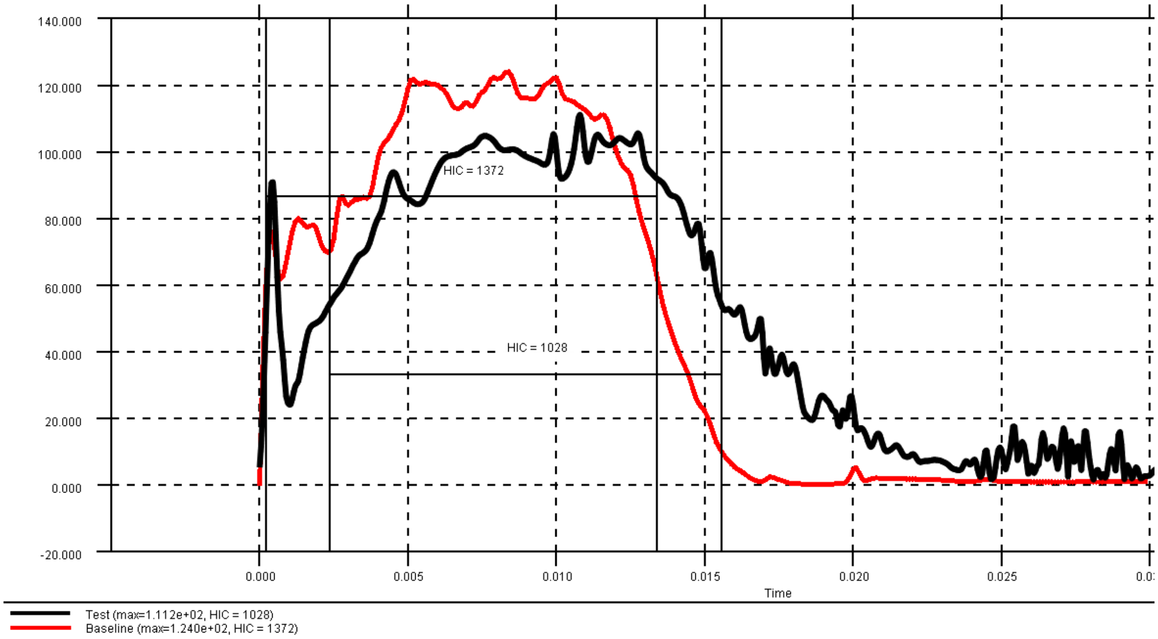


Figure 11 Prediction using the base material model for the windscreen

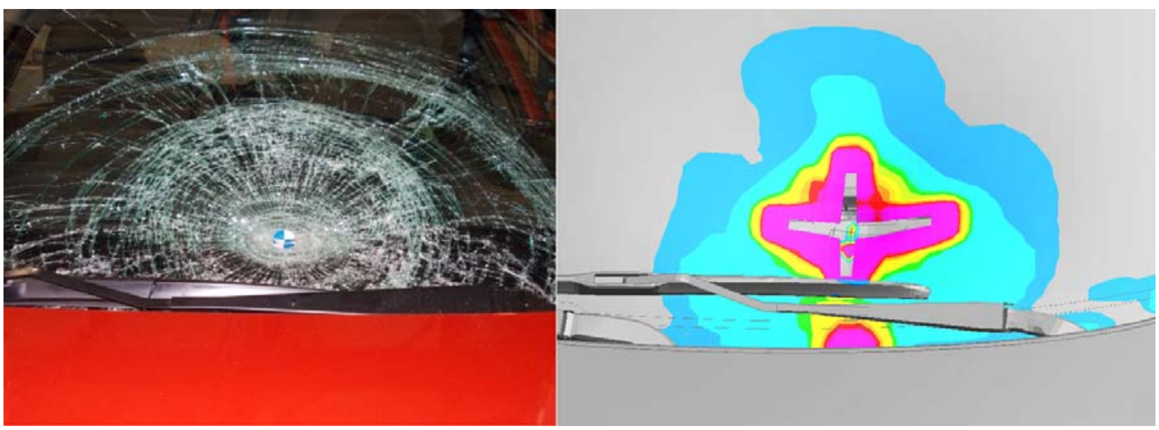


Figure 12 Results with the initial material model

The initial material model used for simulating the behaviour of the windscreen was not able to predict the radial cracking seen in the test. This is important for crack propagation. The model also lacked the capability to predict the tangential cracking pattern that is important to predict the reduce the stiffness of the the windscreen in tension.

By changing the material model, we were able to predict the cracking behavior of the windscreen more accurately. The initial peak at the first crack of the windscreen was difficult to capture but, in general, the behavior of the windsceen model was correlating more closely with the physical test.

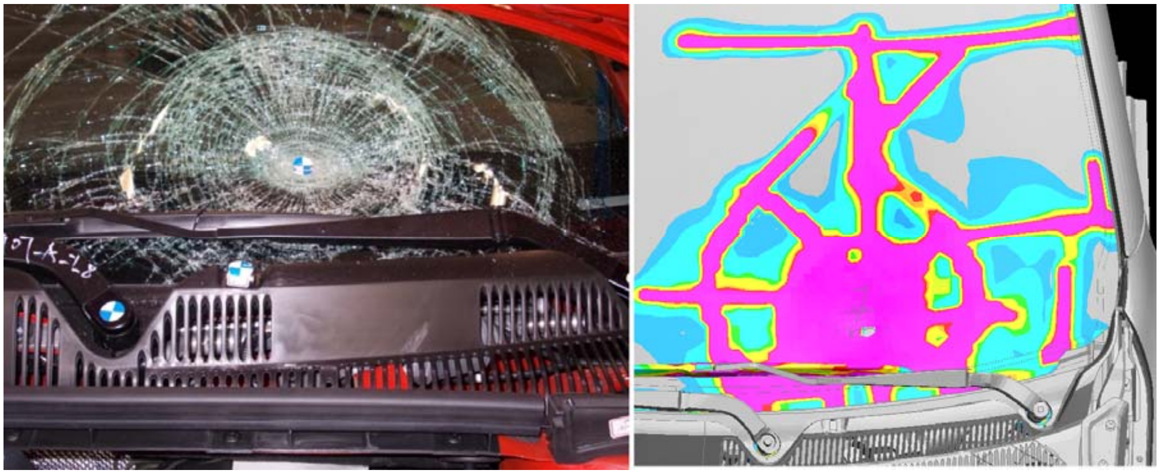


Figure 13 Results with improved failure model for the windscreen

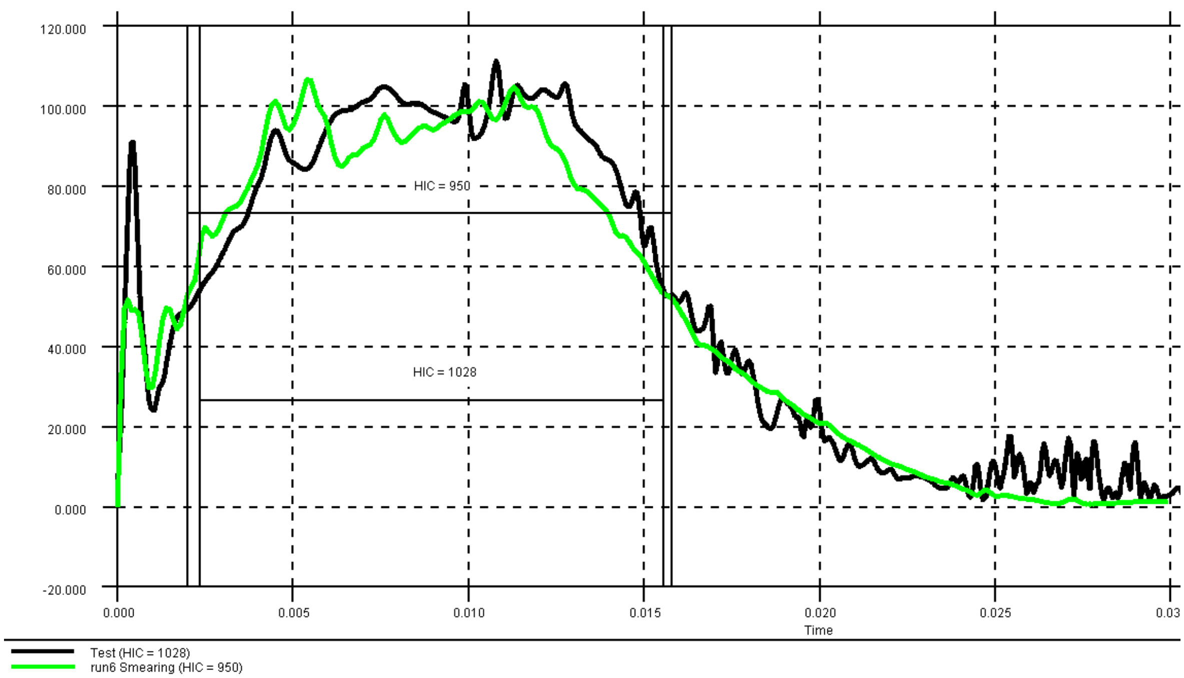


Figure 14 Results after improving the material model used for the windscreen

Final Confirmation from Official Euro NCAP Testing

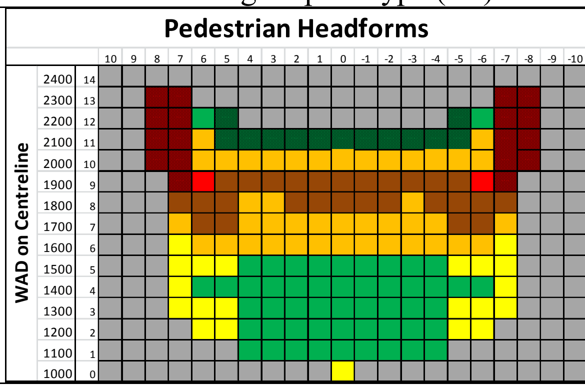
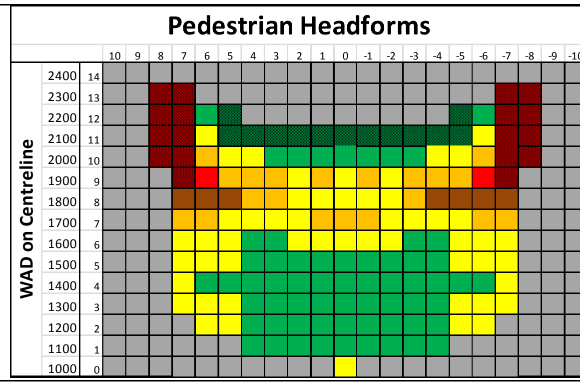
Results from testing on prototype (PT) vehicle	Status Euro NCAP
	

Figure 15 Comparison between initial PT test and final Euro NCAP test results

The outcome of Qoros' strategy, approach and considerable engineering effort in pursuit of the 5-star Euro NCAP rating was presented by Euro NCAP on September 25, 2013.

The 5-star score was of course obtained not only with a good pedestrian protection result, but with an overall safety performance of the vehicle for both front and side impact as well as child safety. We are very proud of what was achieved during the development of the first vehicle from Qoros Automotive.

Not only is the Qoros 3 Sedan the first car developed in China to achieve a 5-star rating, but it also achieved one of the highest scores ever in the organization's 16-year history and was 'the best performer of any car subjected to Euro NCAP's crash tests in 2013'.

Figure 16 Euro NCAP complete vehicle rating

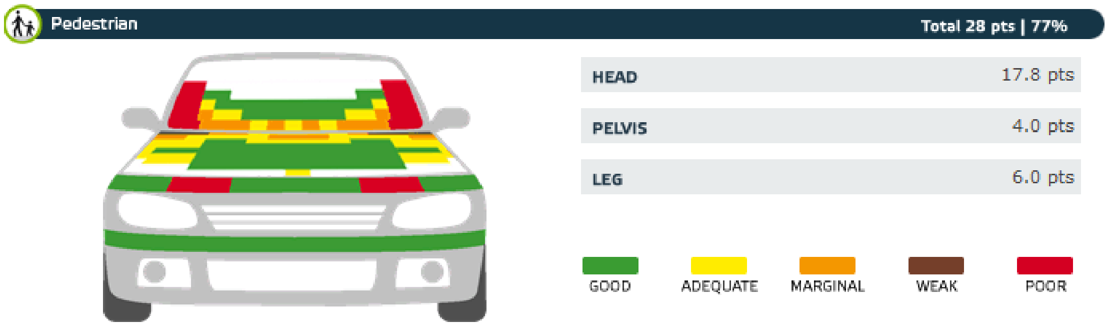


Figure 17 Euro NCAP Pedestrian Rating

For pedestrian protection, the initial targets for each of the 4 different zones (Child and Adult head, upper and lower leg) were either achieved or exceeded. The improved performance can be attributed to the implementation of the final counter measures that have ultimately resulted in a very robust and stable design that proved to perform very well.

References

[1] LSTC, LS-DYNA Keyword User's Manual R6.1.0 (Volume 1 & 2) , 2012
[2] Nguyen, Haufe, Sonntag, Kolling, "Zur Simulation von Sicherheitgls unter stossartiger Belastung Teil I: FE-Modelle fuer Eincsheiben- und Verbundsicherheitsglas", 2004
[3] Haufe, Nguyen,Sonntag,Kolling "Zur Simulation von Sicherheitgls unter stossartiger Belastung Teil II: Validierung eines FE-modells fuer Verbundsicherheitsglas", 2004