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VALIDATION OF EURONCAP FRONTAL IMPACT OF FRAME OFF-ROAD VEHICLE: ROAD TRAFFIC ACCIDENT SIMULATION

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Abstract. The article is focused on the validation of the full-scale virtual model of a frame off-road vehicle. A high degree of coincidence with the real crash test according to EURONCAP rules is achieved. Modeling the processes of high-speed deformation and damage is a complex procedure, requiring a lot of input data parameters and large computing power. The special emphasis is placed on the ways to achieve the coincidence of the behavior of vehicle virtual elements with the behavior of car elements in the full-scale test.
Keywords: crash test, deformation, finite element, validation, vehicle.

1. Background

Frontal crashes of vehicles are responsible for more deaths and serious injuries than any other accident types. A typical scenario is a head-on collision between two oncoming cars at a moderately high speed. In the most collisions of this type, only a part of the vehicle front structure is involved, i.e. the two colliding vehicles are offset. In the full-scale test, the car is driven at 64 km/h with 40 percent overlap into a deformable barrier which represents the oncoming vehicle. The test replicates a crash between two cars of the same weight, both moving at 50 km an hour. Two frontal impact dummies representing the average males are seated in front of the car, child dummies being placed in child restraints in the rear seats.

In this crash, the vehicle structure is put to the test. Limited structural engagement can expose the occupants to increased intrusions. Crash forces have to be efficiently directed to the parts of the car where the energy can be efficiently and safely absorbed. The front crumple zone must collapse in a controlled way, leaving the passenger compartment undistorted as few as possible. Rearward movement of the steering wheel and the pedals must be limited if serious injuries are to be avoided. In Figure 1 the scheme of EuroNCAP frontal crash-test procedure is shown [1].

Computer simulation of traffic accidents is currently the predominant approach in the design of safe modern vehicles. Most of simulations of accident situations are accomplished virtually what allows accelerate developing a design of the cars, while the number of full-scale real experiments is reduced to a minimum. The full-size finite element (FE) model of a car is a complex structure which includes millions of elements; dozens of material models and thousands of different compounds what implies a high complexity of repeating the full-scale real test. Therefore, the first step after the model is created is the detailed comparison of the virtual simulation results with the full-scale test and step-by-step validation [2].

Fig. 1. Scheme of EuroNCAP frontal crash-test procedure.

2. Modeling

The complexity of this work and the difference from other works in this area lies in the lack of initial data; the industrial partner at the beginning of the work did not transfer all the necessary data, such as mathematical models of materials, kinematics parameters of chassis connections, airbags and belts FE models etc, therefore, the model validation procedure was developed in conditions of a lack of original data. In spite of this a good correlation of virtual and real experiment results is achieved.

As a result of modeling the “smart digital twin” was created;– the model which includes all the necessary parameters for prediction of object behavior during any physical interaction. “Smart digital twin” is the integral part of the digital factory, the complex of processes with the aim of achieving the new level of designing products, structures and approaches to production through the effective use of the entire complex of multi and transdisciplinary technologies of the world level.

The production of 2016 four-door passenger SUV was used as the basis for the model. CAD-models of the full vehicle were provided by the customer. Each part was meshed to create a representation of geometry models for finite element modeling that reflected all structural and mechanical features in a digital form. The parts were broken down into elements in such a way that critical features were consistent with the implications of element size on simulation processing times. Material characteristics data for the structural components were obtained through testing real samples. Based on material testing, appropriate stress, strain and damage values were included into the model for analyzing the crush behavior in a crash simulation. The experiment results were provided by the customer.

The resulting FE vehicle model has 3 million elements. This detailed FE model was constructed to include the full functional capabilities of a suspension, a driveline and steering subsystems. The representation of the model in comparison with the actual vehicle is shown in Figures 2 and 3. The set of elements representing the vehicle was translated into an FE model by defining each as a shell, a beam, or a solid element in accordance with the requirements for using LS-Dyna software. As the result of these efforts, the finite element vehicle model was designed with the following characteristics: number of parts 3544, number of nodes 3 million, and number of elements 3 million. The average element size used is 8 mm with a minimum size of 4 mm.

Fig. 2. Actual vehicle.

Fig. 3. Full scale FE representation.

Modeling detailed all the components of an off-road car. Figure 4 provides the bottom view of the vehicle model. The engine is modeled with a coarser mesh, because the previous simulation experience has shown that it reacts as a large rigid mass in crashes. It is modeled with external shell elements and mass elements having weight and inertia the same as the actual engine. The limp mass representation of the engine and the suspension elements can also be incorporated into the model.

Figures 5 and 6 illustrate the view of the modeled front and rear suspension systems. The moving parts are detailed to provide the capability for simulating suspension and steering responses. All inner components of the front and rear doors are incorporated into the initial version of the model and are presented in Figure 7. Structural components of the vehicle interior are included in the initial version of the model and shown in Figure 8.

To estimate the injuring criteria of a driver and a passenger according to EURONCAP requirements, the model includes validated commercial models of Hybrid-3 50% dummies corresponding to the actual experiment. Figure 9 shows the FE model of dummies.

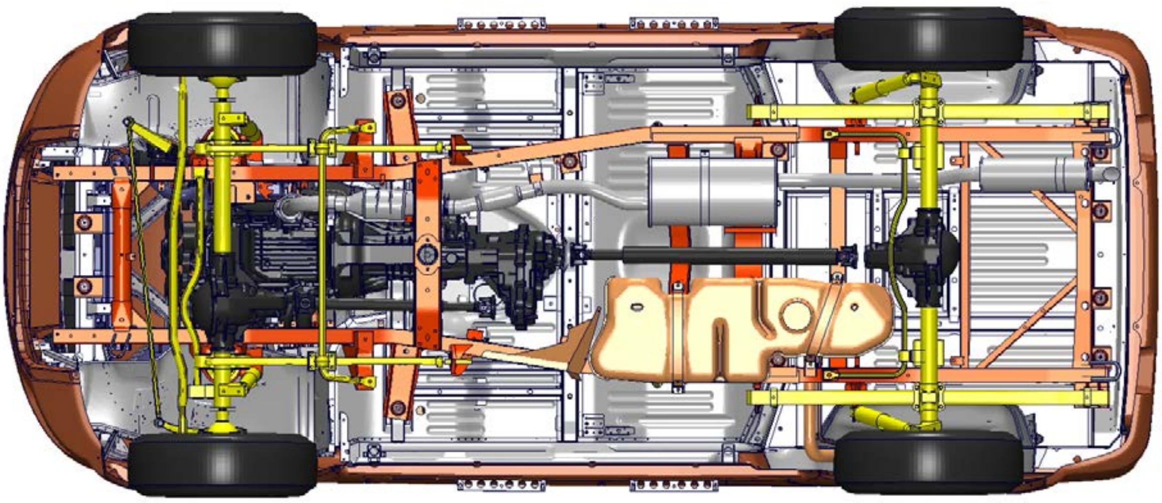

Fig. 4. Vehicle model bottom view.

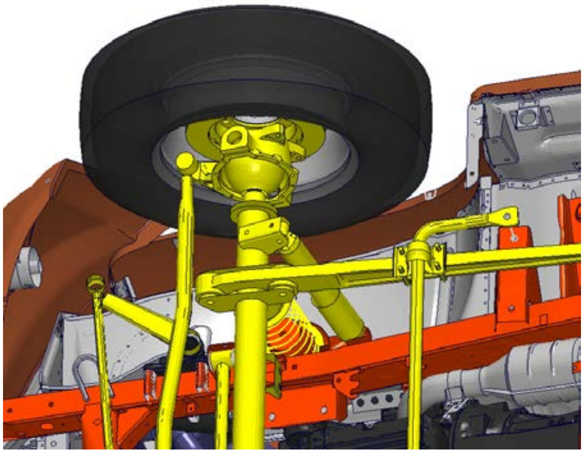

Fig. 5. Modeled front suspension.

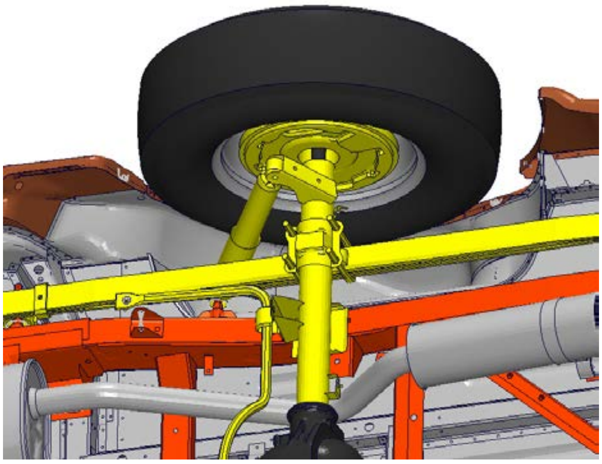

Fig. 6. Modeled rear suspension.

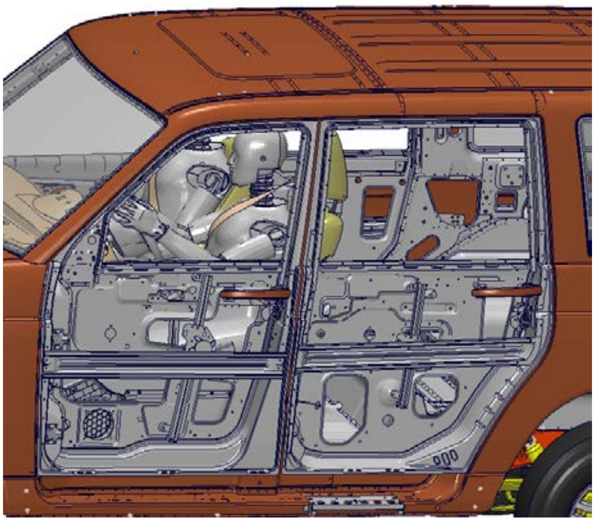

Fig. 7. Details of interior door components.

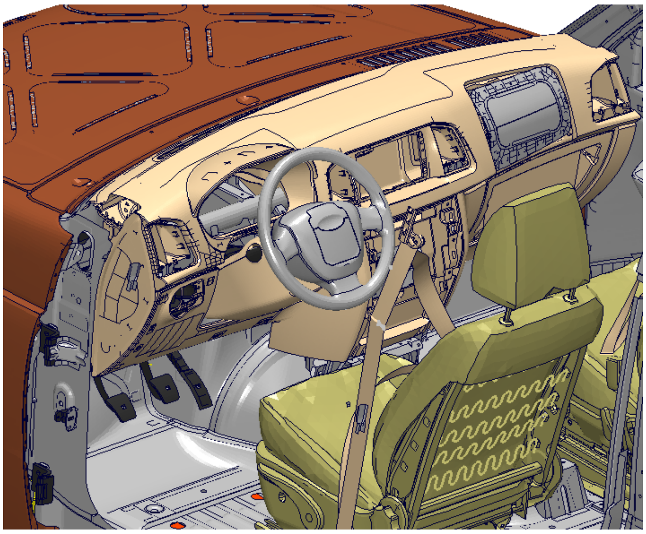

Fig. 8. Coarse representation of structural interior components.

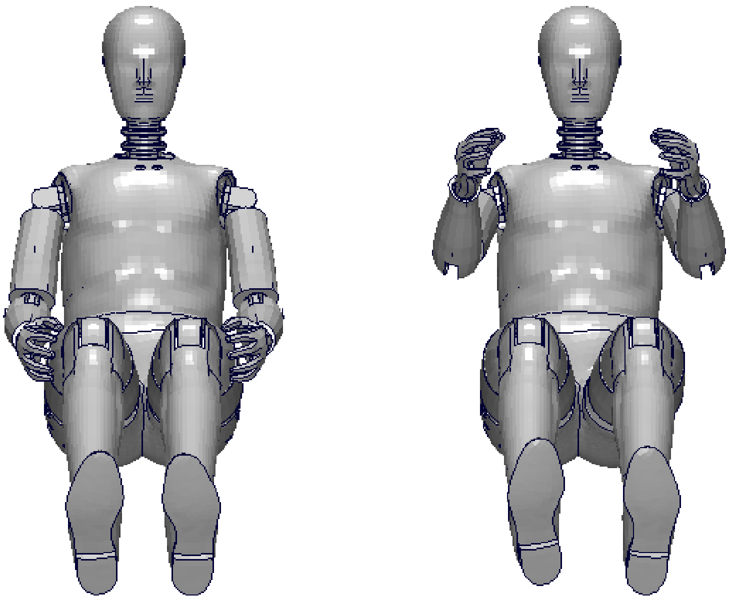

Fig. 9. FE models of driver and passenger dummies.

3. Model validation

The FE model was validated in various ways to make sure that it was an accurate representation of the actual vehicle [3, 4]. The initial efforts included checks for completeness of elements and adequacy of connection details. The measured properties at customer location for the vehicle were compared to those generated from the FE model. The results are given in Table 1.

Table 1. Comparison of measured properties of actual and modeled vehicle.

Property	Actual Vehicle	FE model
Weight, kg	2308	2308
Vehicle COG Z, mm	802	802
Vehicle COG X, mm	1492	1492
Clearance, mm	210	210
Width (without mirrors), mm	1900	1900
Length, mm	4785	4785
Height, mm	2005	2005
Wheelbase, mm	2760	2760

The FE model EuroNCAP simulation was performed using the LS-DYNA non-linear explicit finite element code. The FE vehicle model was run using LS-DYNA Code. The FE model response would be expected to vary for other facilities depending on hardware, LS-DYNA version, and precision used. The variations are typically minimal and the results from the different versions are comparable. The total duration of the simulation was 200 ms to capture the initial impact until the rebound of the vehicle from the EuroNCAP load.

Due to the lack of data provided by the manufacturer, the first virtual tests according to the EURONCAP rules had a low degree of correlation with the full-scale crash test. The following data were not provided:

- results of testing plasticity and damage of a car body and frame materials, taking into account viscous properties and high-speed deformations curves;
- stiffness and damping curves of kinematic connections in suspensions;
- shock absorber behavior data;
- kinematic parameters of the engine, gearbox and cardan;
- virtual model of airbags and seat belts./

To select appropriate material models, a series of crash simulations was performed in order to achieve deformation coincidence. The customer provided the material models that do not take into account high-speed hardening; therefore, at high strain rates, deformations significantly exceeded the values reached in the actual EuroNCAP test.

Figure 10 shows deformations for a body with materials that do not take into account high-speed hardening, Fig. 11 shows body deformations with selected material from the database of contractor, with strain-stress curves for high-speed deformations. For comparison Fig. 12 shows deformation from actual crash impact. As a result of the multivariant optimization, it was possible to achieve a similar character of deformation of the frontend, the body sill, and the doors of the off-road vehicle.

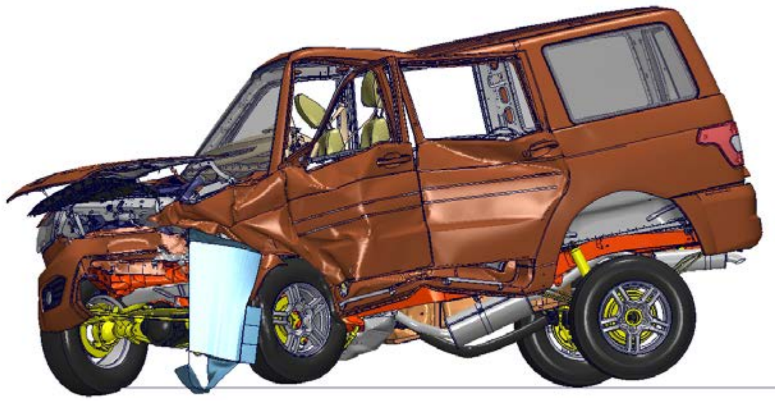

Fig. 10. Deformation with customer material models.

Fig. 11. Deformation with optimized material models.

Fig. 12. Deformation in actual crash-test.

One of the features of the vehicle crash test is the rotation of the front wheel, and its subsequent intrusion into the car floor with subsequent disruption of the living space integrity for a driver and passengers. With the view of simulating this effect correctly, a detailed multivariate adjustment of parameters of the front suspension and front axle of the off-road vehicle in the kinematic MBS (Multi Body System) model was performed, and then all the chosen parameters were transferred to the full-scale LS-Dyna FE model. The adjusted front suspension model includes all the kinematic parameters of the bushings, wheels and suspension. Figure 13 shows the performed tests of the front suspension in MBS model. Figure 14 and 15 shows the position of the wheel in 150 ms in the model with unconfigured suspension and in the model with the adjusted suspension.

Virtual model of airbags and seat belts were not provided by customer, so they were adjusted according to EuroNCAP test results. In Figures 16 and 17 one can see comparison of driver airbag behavior in simulation and in the actual test at the moment of head collision with surface of airbag on 90 ms. Figure 18 exhibits the side view of the frontal deformations taken at five intervals during the impact. It can be noted that the actual and simulated views reflect similarity at each time point.

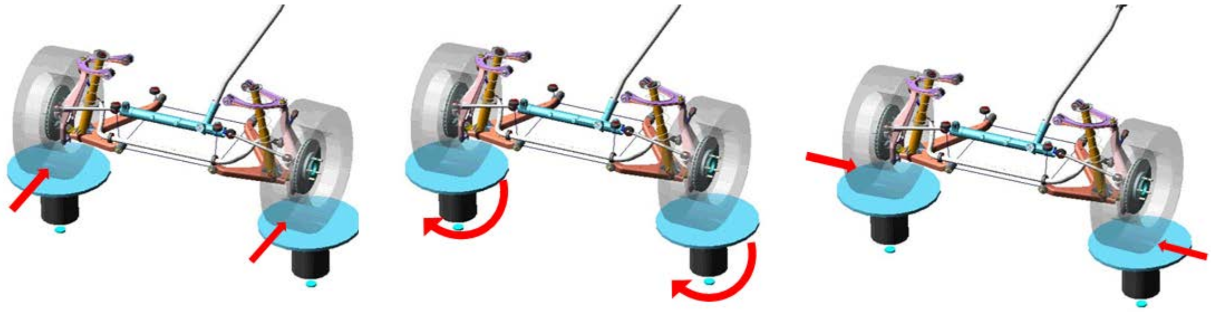

Fig. 13. Frond suspension MBS model adjusting.

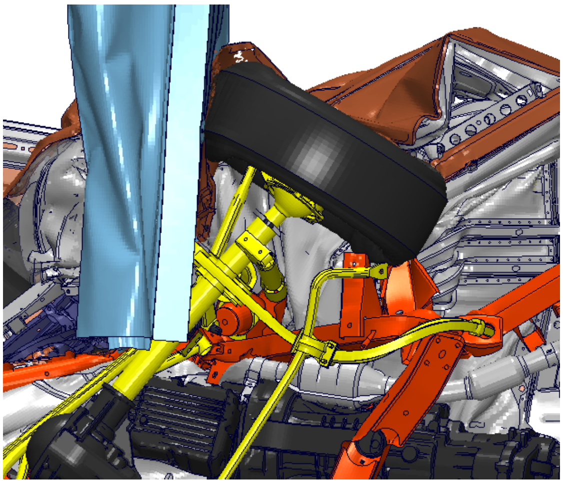

Fig. 14. Front suspension behavior during the initial virtual crash-test.

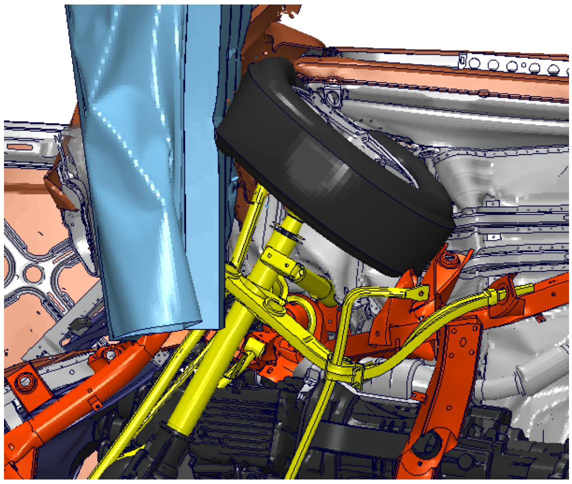

Fig. 15. Front suspension behavior during the virtual crash-test with adjusted and configured parameters.

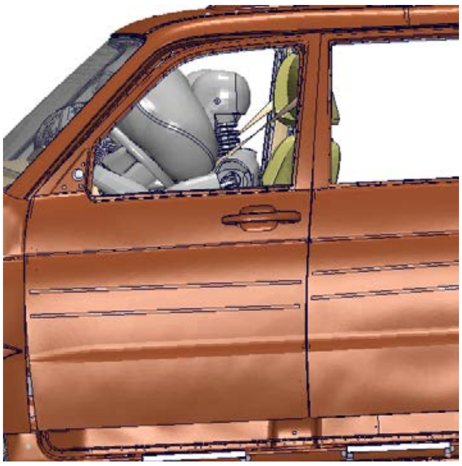

Fig. 16. Collision of dummy head with airbag, virtual crash-test 90 ms.

Fig. 17. Collision of dummy head with airbag, actual crash-test 90 ms.

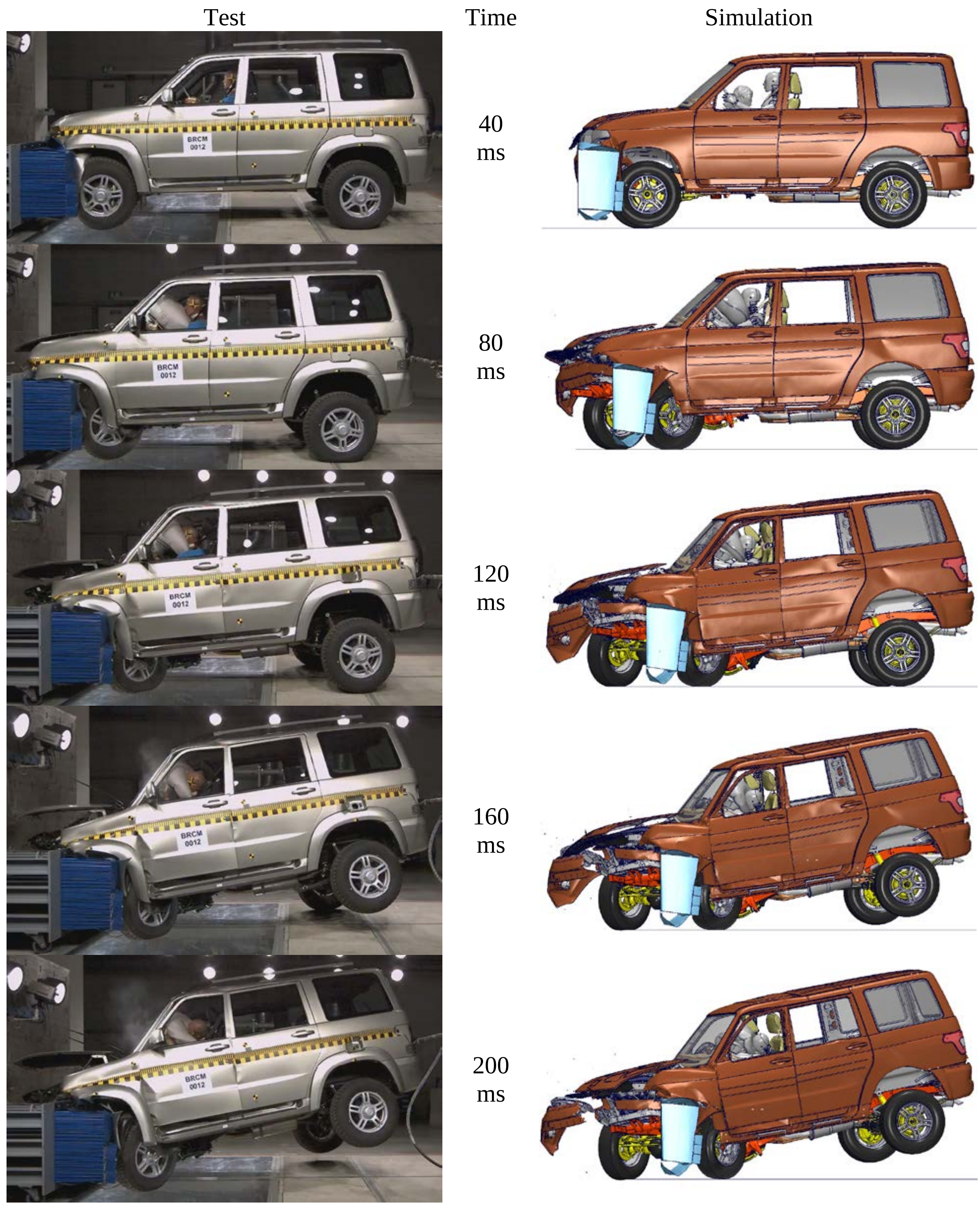

Fig. 18. Sequential side views of the actual and simulated EuroNCAP frontal deformable barrier test for the off-road frame vehicle.

The side view shows a high degree of deformation coincidence of the vehicle front part. In both cases the hood does not interact with the barrier and ejects forward due to high inertial forces. The fenders and front part of car body have almost identical deformations. The rear part of the vehicle rises up in both tests due to the high position of center of gravity.

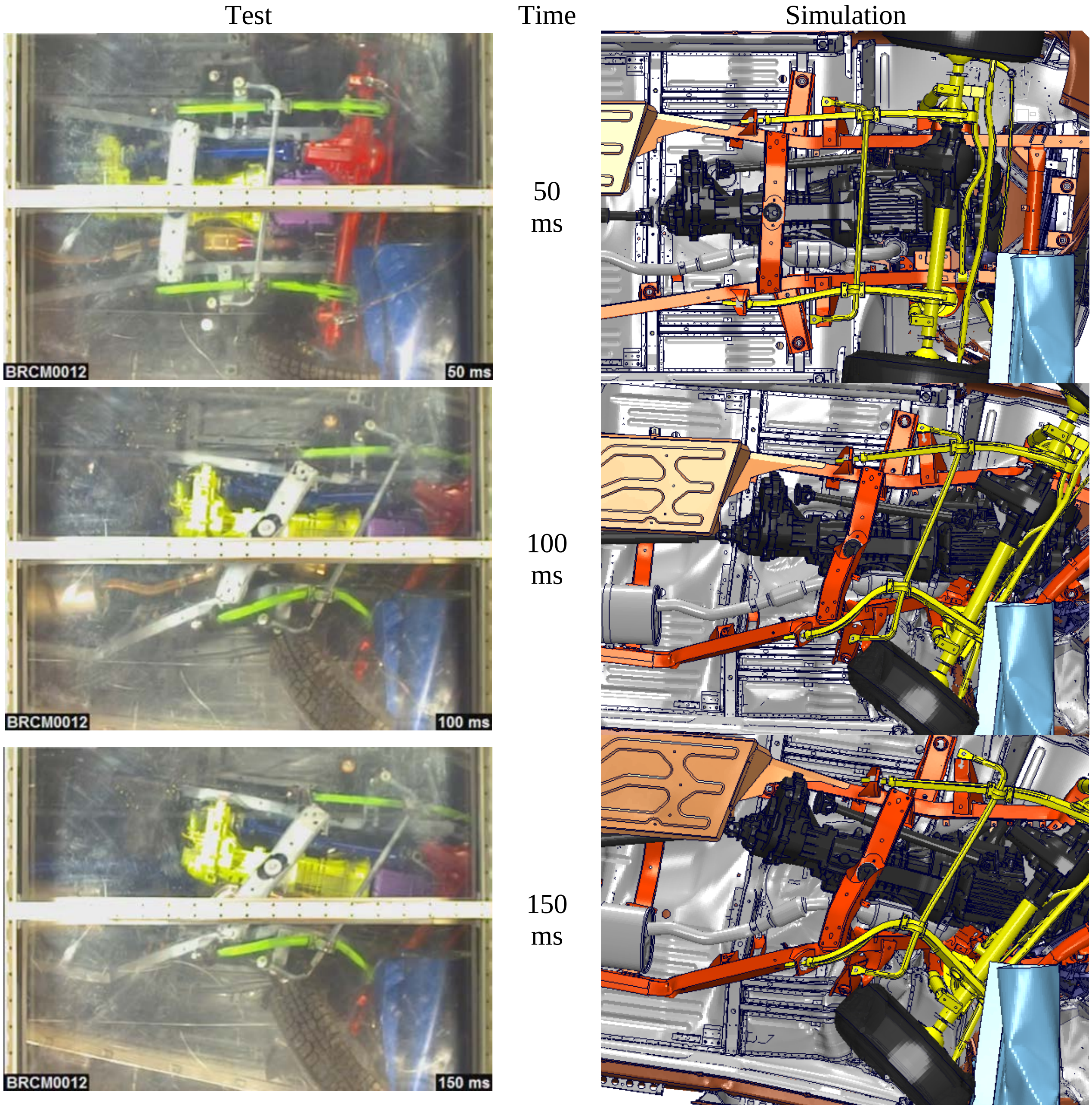

Fig. 19. Sequential bottom views of the actual and simulated EuroNCAP Frontal deformable barrier test for the off-road frame vehicle.

Figure 19 shows the bottom view of the frontal deformations taken at three intervals during the impact. There is a high degree of coincidence of frame deformations in full scale and virtual tests. One can see that fractures appear in the same places, the deformation paths have a similar pattern, the fastening point between the torque divider and the front cardan is broken in both cases, and the same support damage between car body and frame can be noticed. In both cases, the front wheels rotate with the subsequent destruction of the car body floor and a breakdown of the integrity of the living space of a driver and passengers.

Figure 20 illustrates the top view of the frontal deformations taken at three intervals during the impact. The top view for full scale and virtual tests demonstrate the same turning angle of the vehicle after the impact, the similar picture is for opening the hood and deformation of the left wing.

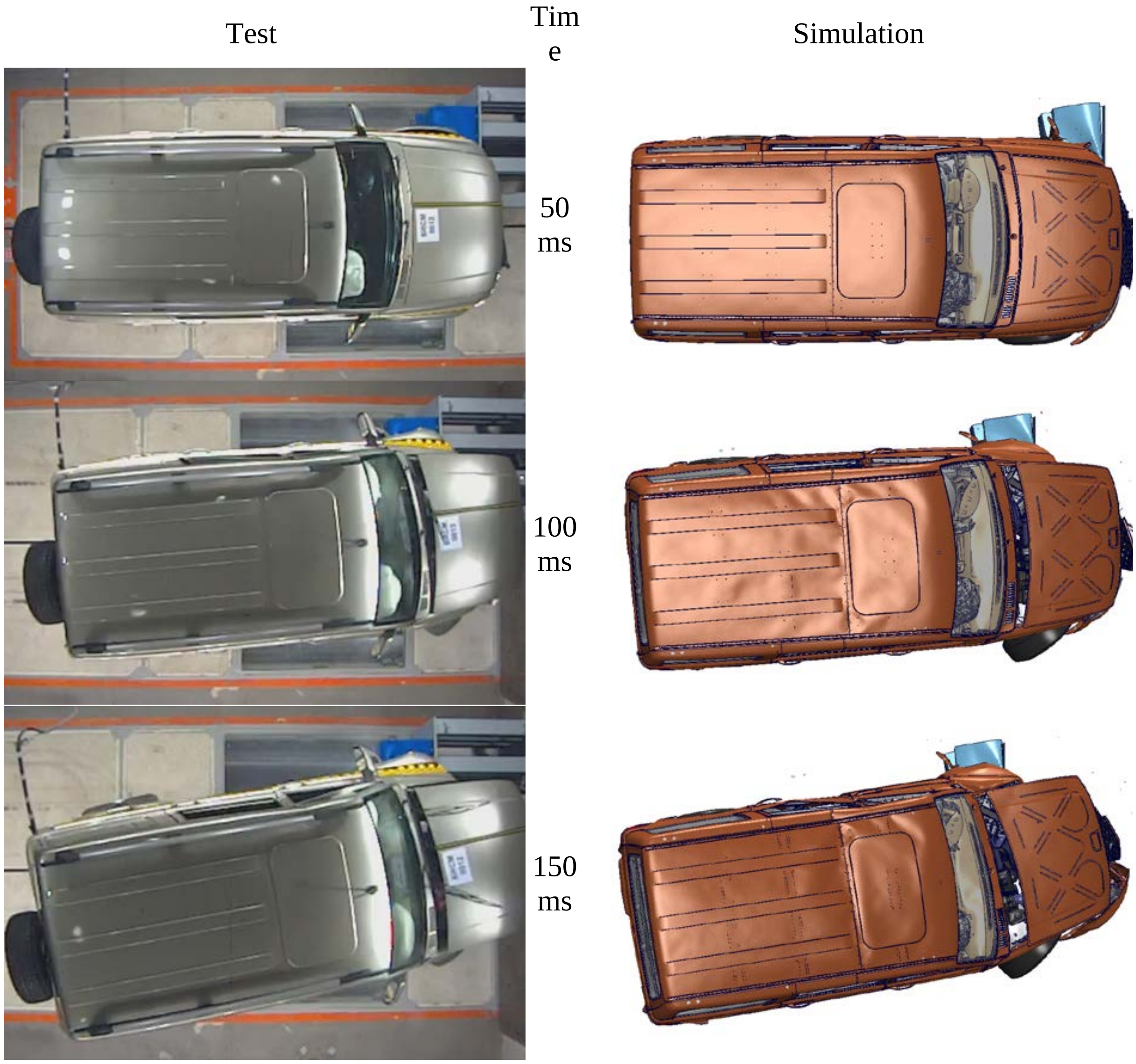

Fig. 20. Sequential top views of the actual and simulated EuroNCAP frontal deformable barrier test for the off-road vehicle frame.

4. Summary and conclusions

A FE model of the 2016 passenger SUV was created and validated using LS-Dyna solver. Modeling led to a detailed model that consists of 3 million elements, includes all vehicle structural and interior components, and has functional representations of the steering, suspension and driveline systems. A multistage process of selecting the missing characteristics was carried out. As a result of the iterative process of validation of off-road vehicle model, a high degree of coincidence with the full-scale test is achieved. Missing characteristics of SUV were selected and fitted during the validation process, the selected characteristics showed a sufficient degree of correlation. The final model will be used to conduct virtual tests to determine the passive safety according to EURONCAP rules in the process of developing the off-road vehicle for future production.

The model was validated by comparison to images and data derived from the customer, which involved actual frontal impact into a deformable barrier at 64 km/h according to EuroNCAP rules. Comparisons of data from the test and the model included:

- Measurements checks : length, width, height, clearance and wheelbase;
- Weight and coordinate of gravity center;

- Deformation of car body and frame from side, bottom and top views;
- Wheel rotation during the impact with subsequent intrusion to the living space of a driver and a passenger;
- Behavior of front suspension and front axle during the process of impact

All the comparisons showed overall good correlation with the physical test results. Validated model is approved by the manufacturer and will be used as the basis in further frontal impact virtual tests during the development of a new off-road vehicle.

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