EXPERIMENTAL VALIDATION OF THE NUMERICAL MODEL OF A CAR IMPACT ON A ROAD BARRIER

Wiesław Barnat, Paweł Bogusz, Paweł Dziewulski, Roman Gieleta
Andrzej Kiczko, Marian Klasztorny, Tadeusz Niezgoda, Stanisław Ochelski

Military University of Technology, Faculty of Mechanics
Department of Mechanics & Applied Computer Science
Kaliskiego 2 Street, 00-908 Warszawa
tel.:+ 48 22 683 94 61
e-mail: wbarnat@wat.edu.pl, pbogusz@wat.edu.pl, pdziewulski@wat.edu.pl, rgieleta@wat.edu.pl
akiczko@wat.edu.pl, mklasztorny@wat.edu.pl, tniezgoda@wat.edu.pl, sochelski@wat.edu.pl

Abstract

This analysis considers the problem related to the transport safety improvement by applying specialized energy absorbing elements. The advanced finite element method was used to solve this problem. The obtained results permit to estimate the practical usability of the proposed solution.

In previous works of the examination team [1-5] a series of numerical analysis of the car – road barrier dynamical system, directed to the elaboration of the numerical model methodology of an impact problem with the use of chosen CAE programs, was submitted. In this article experimental results of a Suzuki Swift car impact into a standard road barrier are presented. Tests were carried out at the Automotive Industry Institute (PIMOT) in Warsaw, with the use of a test sample of the road barrier. Presented results of experimental tests serve to validation of a numerical model of the aforementioned system. For the safety sake the car's speed during the experimental examinations was limited to 50 km/h. Moreover, the vehicle hit perpendicularly a properly modified road barrier's sector. Experimental initial boundary and constructional conditions were modelled in numerical examinations, in which a commonly available Suzuki Swift car model, http://www.ncac.gwu.edu, was used. Numerical analysis was carried out with the use of LS-DYNA system.

Keywords: *car – road barrier system, crash test, experimental examinations, numerical simulations, numerical model validation*

1. Description of the stand and the object of experimental crash tests

Experimental crash tests of the system car-road barrier (C-G) were carried out in the Vehicle Safety Laboratory of the Automotive Industry Institute in Warsaw (Fig. 1).

Fig. 1. Stand for vehicle crash tests with a barrier in PIMOT's Vehicle Safety Laboratory

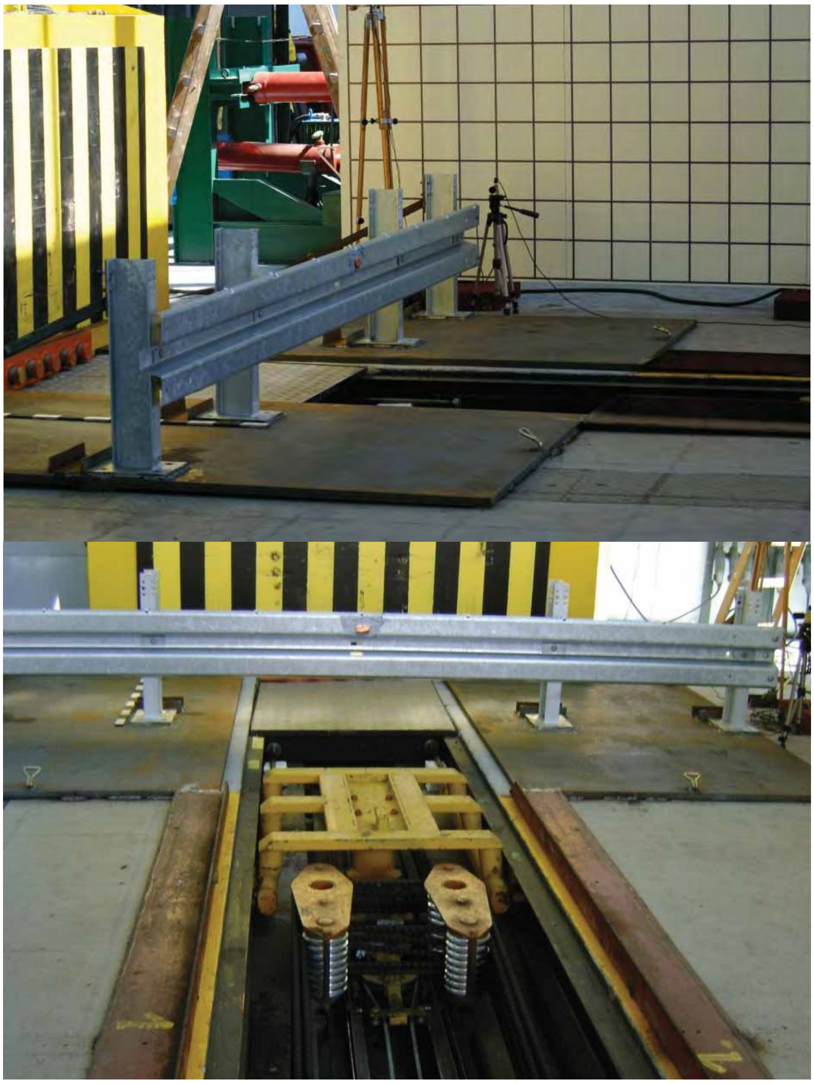

Fig. 2. Examined road barrier construction on the examination stand

The examination stand, in the Vehicle Safety Laboratory of PIMOT, enables carrying out crash tests of vehicles with a barrier (guardrail). For the sake of safety it is only possible to carry out tests with a perpendicular impact to the road barrier's surface. The tested vehicle is hitched to a special platform that is accelerated on the track with a help of a catapult. The catapult enables carrying out impact of whole vehicle weighting up to 2500 kg with a speed to 65 km/h. Before the impact, the car is released from the platform and with the force of impetus hits the barrier. The test is registered with the use of cameras designed for fast shooting. During the test measurements of accelerations are performed with the use of acceleration sensors respectively placed in the car. In the examined vehicle a driver manikin is also placed.

For crash tests a protection barrier composed of guide poles type B and bridge posts IPE140 was chosen. The examined construction is visible in Fig. 2. Spacing of posts was conditioned by the specificity of the examination stand. The distance between middle posts was 2 m, and the distance between side posts equalled to 1 m. Posts of the road barrier were welded to two steel plates. The plates were fixed to a retaining wall and affixed to the base.

The test was registered with the use of three cameras designed for fast shooting. Two of them registered the image from one side, the third one from top (Fig. 3). Basing on the registered images it is possible to determine: the car's speed before the impact and displacements of chosen points of the tested road barrier.

The Suzuki Swift car, weighting 688 kg (depicted in Fig. 4), was prepared for the crash test.

Fig. 3. Cameras for recording the test's course spacing

Fig. 4. Suzuki Swift car used in the crash test

2. Experimental tests results

A crash test course of the system C-G was registered with the use of two cameras for fast shooting (Fantom v12). Image was recorded in resolution 1280x800 pixels with frequency 1000 shots per second. The shot exposure time was 250 microseconds. The selected shots from the crash test are presented in Fig. 5, whereas the protective road barrier deformation was presented in Fig. 6.

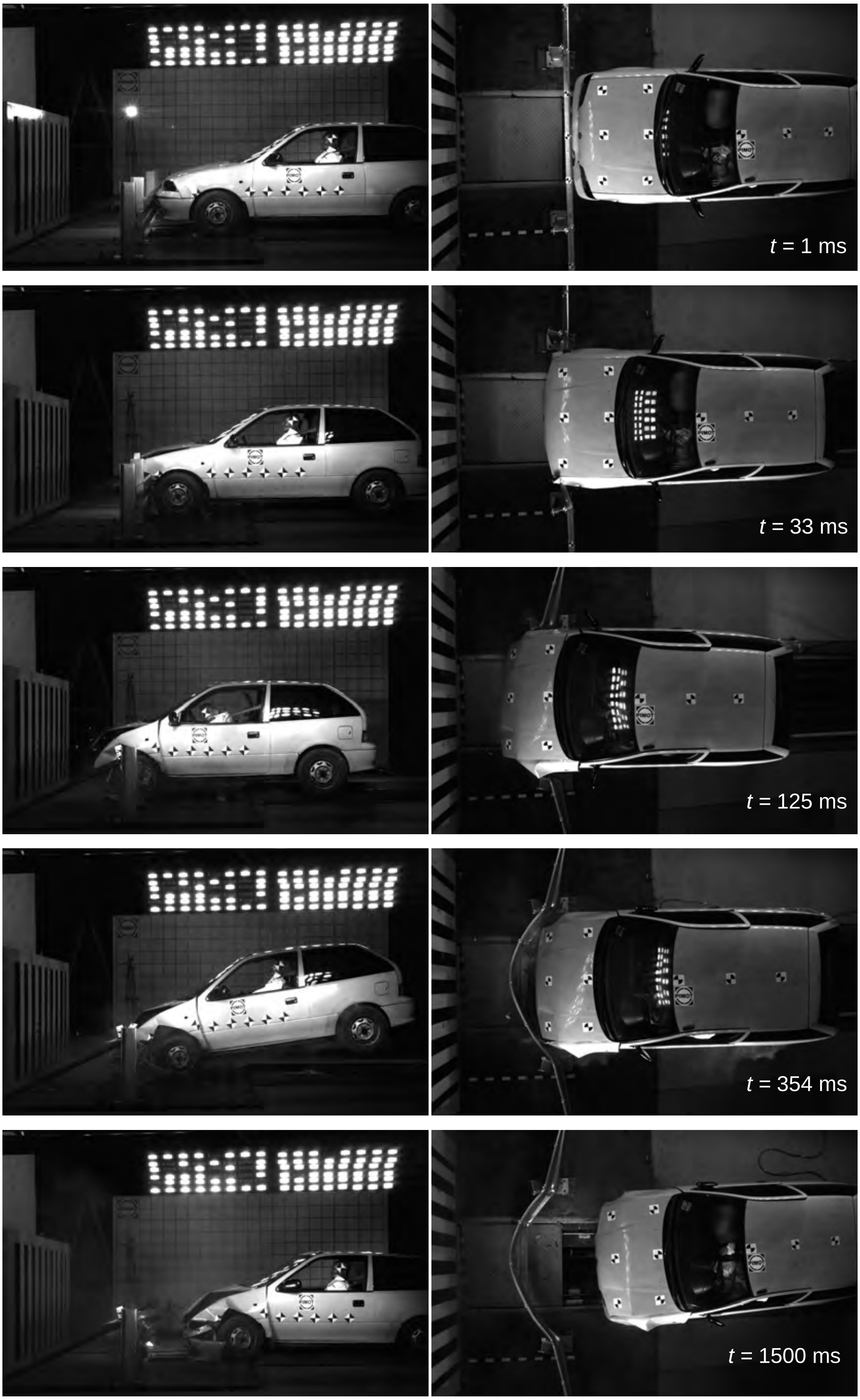

Fig. 5. The crash test course registered with the use of two synchronized cameras designed for fast shooting (FANTOM v12)

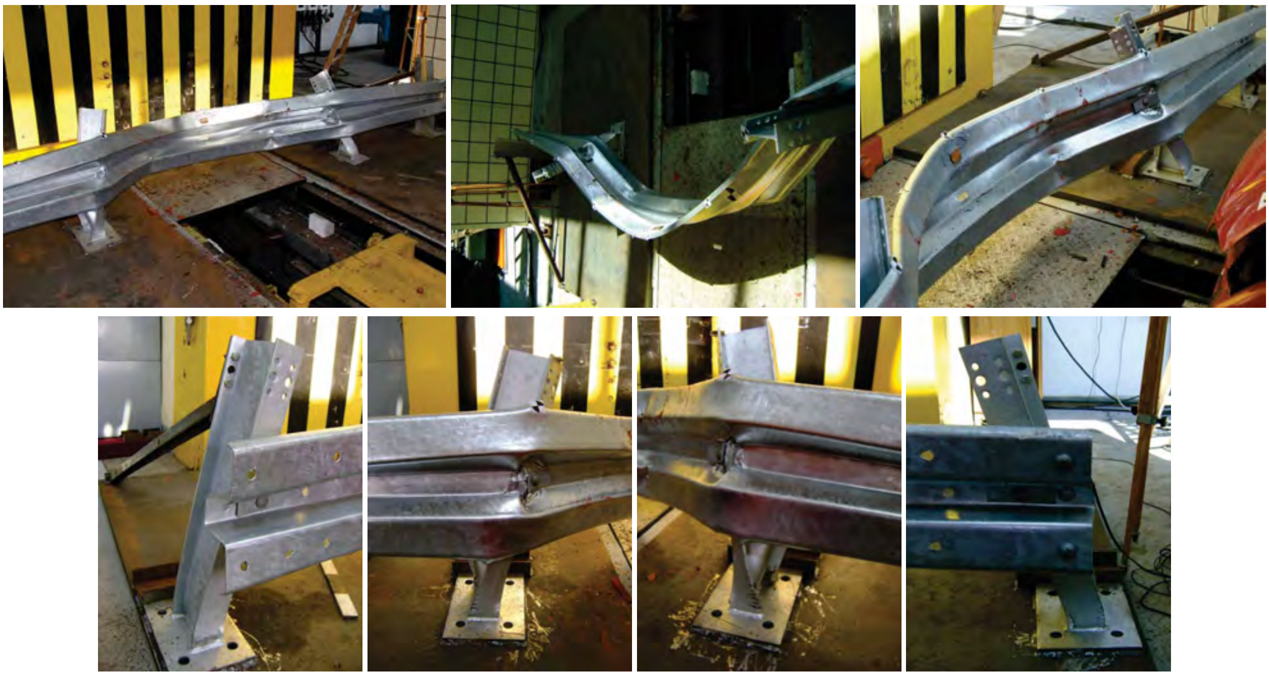

Fig. 6. Deformation of the tested protective road barrier

Basing on the image from the upper camera with the use of TEMA programme the permanent total displacements (on the horizon plane) of the markers, placed on the road barrier, were determined. They were marked in Fig. 7 with numbers from 1 to 7. They amount to:

- point no. 1 – 205 mm,
- point no. 2 – 309 mm,
- point no. 3 – 575 mm,
- point no. 4 – 695 mm,
- point no. 5 – 527 mm,
- point no. 6 – 267 mm,
- point no. 7 – 185 mm.

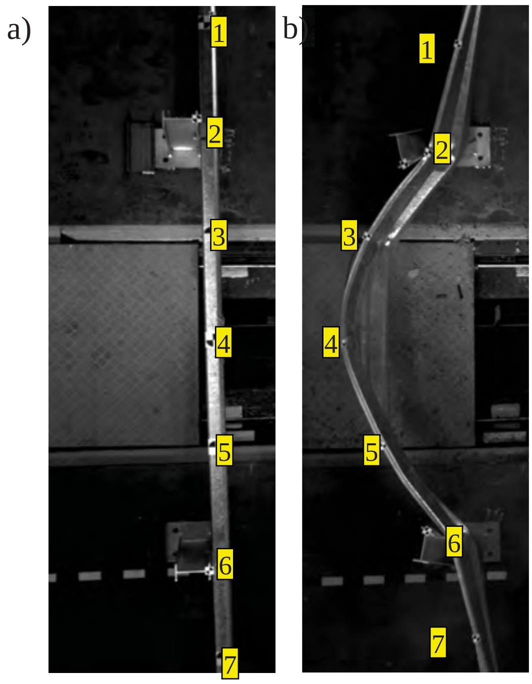

Fig. 7. Road barrier before (a) and after (b) the carried out test with marked points, for which a displacement was specified basing on the TEMA programme of shot analysis

The examined car deformation is presented in Fig. 8. During the test a registration of acceleration was carried out by the acceleration sensors placed in the car (among others on the centre of gravity and over the rear axle of a car). Deceleration components' courses „in the impact direction" registered during the test are presented in Fig. 9. Maximal value of the acceleration on the centre of gravity is 26 g, and over the rear axle is 20 g.

Figure 10 presents resultant acceleration courses coming from the sensors spaced on the driver manikin. The maximal manikin's head acceleration value is 31 g, and the manikin trunk acceleration reaches maximal value of 24 g.

Fig. 8. Suzuki Swift car's deformation

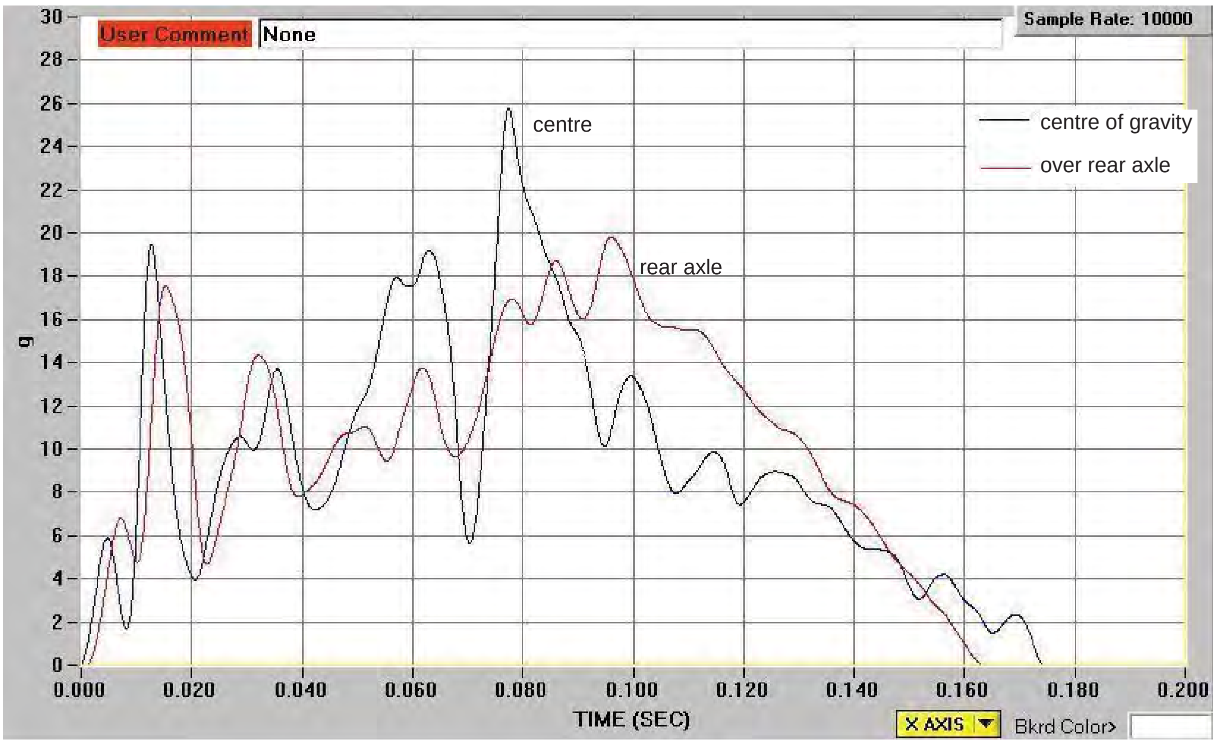

Fig. 9. Diagrams of deceleration constituents' courses „in the impact direction" (of chosen points) – Suzuki Swift

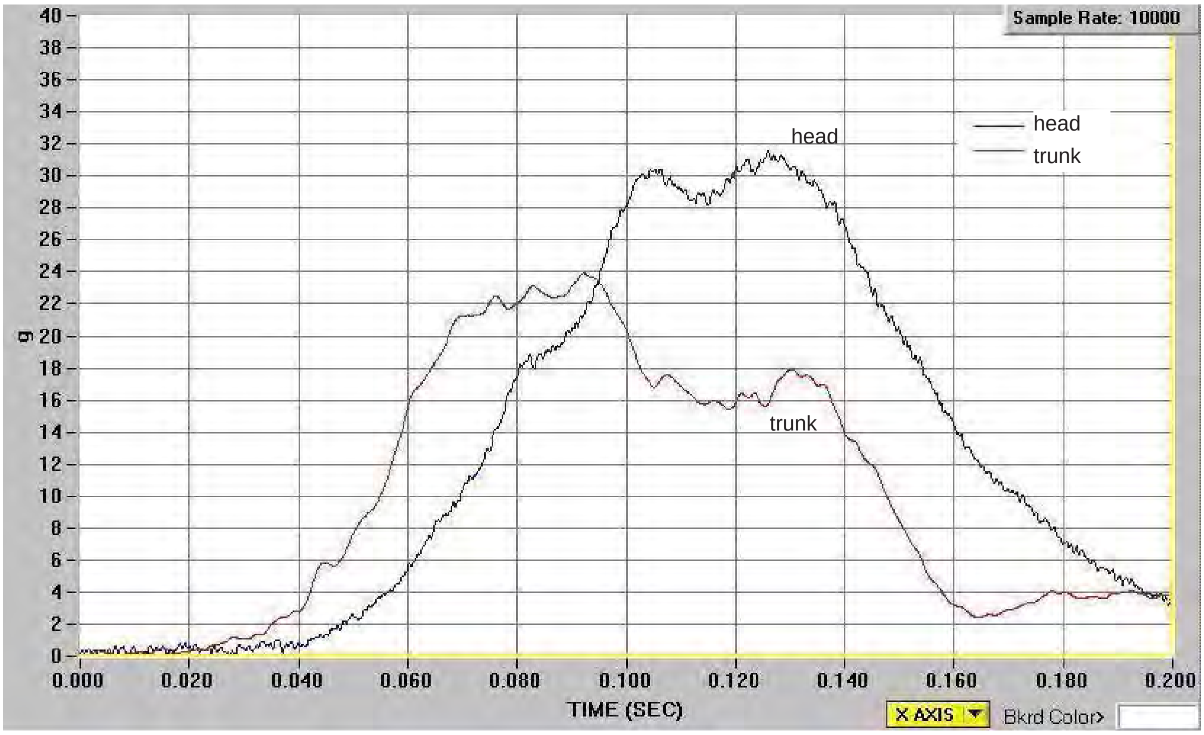

Fig. 10. Diagrams of the chosen resultant deceleration courses – Manikin HII

3. Numerical model description of C-G system

3.1. Numerical model of Geo Metro (Suzuki Swift) car

The Geo Metro (Suzuki Swift) car, commonly available model from National Crash Analysis Center (NCAC), was used for numerical analysis of the car-barrier system. The general view of the car model is presented in Fig 11.

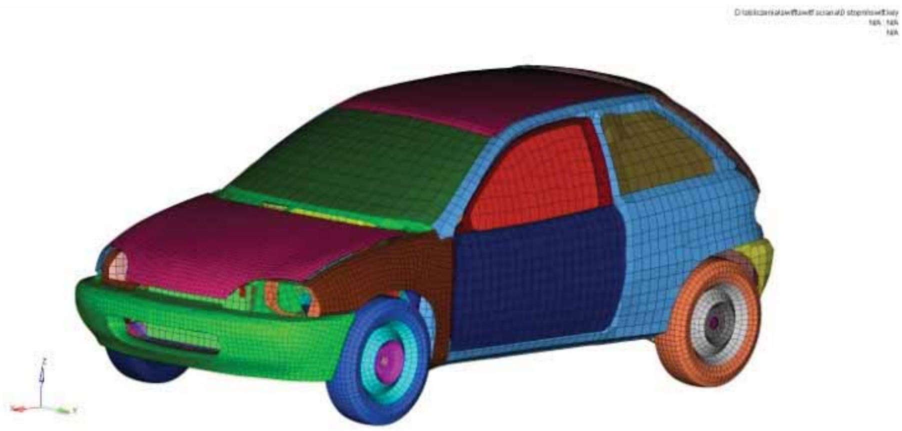

Fig. 11. General view of the examined vehicle numerical model

The car model is composed of 820 elements of SOLID type (with which parts were modelled, among others: an engine block, brake disks, radiator) and 26120 SHELL type elements.
In the model there are 209 parts which are connected with each other by nodes:
- CONSTRAINED_SPOTWELD;
- CONSTRAINED_NODAL_RIGID_BODY;
- CONSTRAINED_JOINT;
- CONSTRAINED_RIGID_BODIES;
- CONSTRAINED_EXTRA_NODES.

Among the vehicle individual elements and between a vehicle and the barrier the contact with friction occurs.

For the material description of most of the parts a flexible-plastic material model with a consolidation was used which takes into account the speed of deformations of MAT-PIECEWISE-LINEAR-PLASTICITY type. Less important model elements are described with a flexible material of MAT-ELASTIC type. Moreover, in the numerical analysis non-deformed elements, described with a material model of MAT_RIGID type, was used. The car suspension elements take into account elasticity and damping and have been modelled with the use of following materials: MAT-SPRING-ELASTIC and MAT-DAMPER-VISCOUS.

Additionally, during the numerical analysis, terrestrial gravity and friction between a base and car tires were taken into account.

3.2. Numerical model of C-G system

The numerical model is composed of Suzuki Swift car and a fragment of SP-04 road barrier (Fig. 12). The model of the fragment of SP-04 barrier contains 7380 elements of SHELL type. The model takes into account material destruction and destruction of the elements connecting posts with the belt. The friction between barrier elements and between the barrier and the car were also taken into account. Initial boundary conditions for the numerical analysis were the same as for the experimental tests.

4. Numerical simulation results

Obtained results from the SP-04 barrier deformation analysis are presented in Fig. 13 and 16. In the analyzed case the car hit the SP-04 barrier at the angle of 90° with an initial speed equal to 52.5 km/h. The use of flexible connections (of individual elements of roadway) with the destruction model caused „an entry" of the vehicle into the roadway. The guardrail's belt resistance prevented the vehicle to leave outside the protective array. This effect is desirable in the aspect of the road traffic safety.

The comparison of accelerations is presented in Fig. 14 and 15. Basing on the obtained results from the car impact into the guardrail the energy was determined, that was dissipated on the guardrail's elements (as a result of deformation).

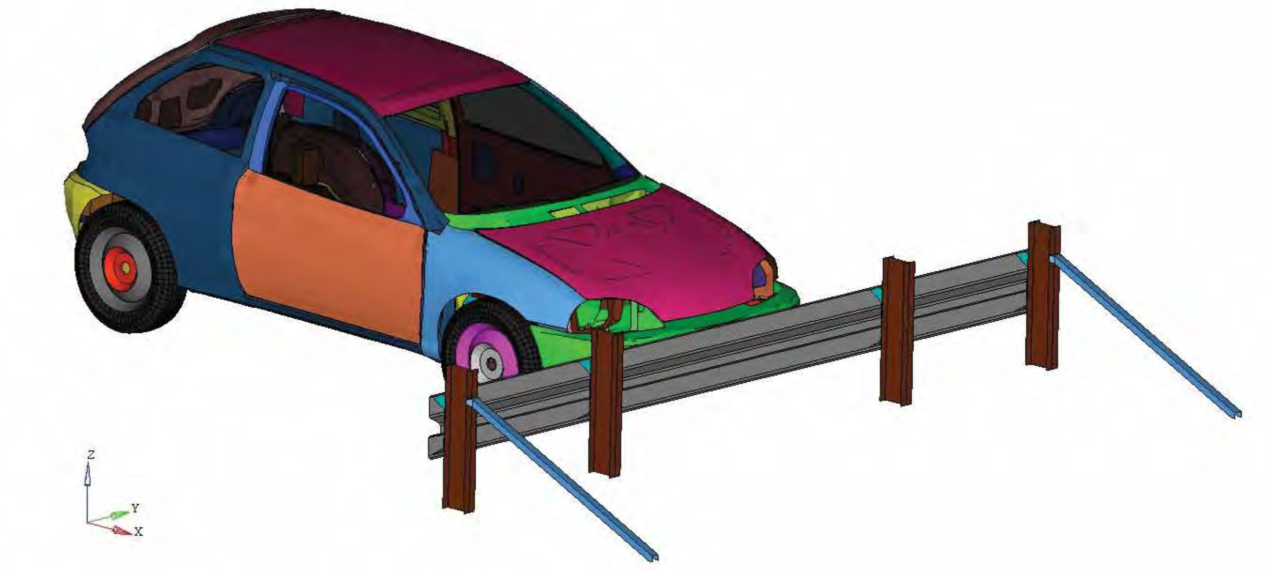

Fig. 12. General view of the model; Car-Guardrail system at the instant t=0 s

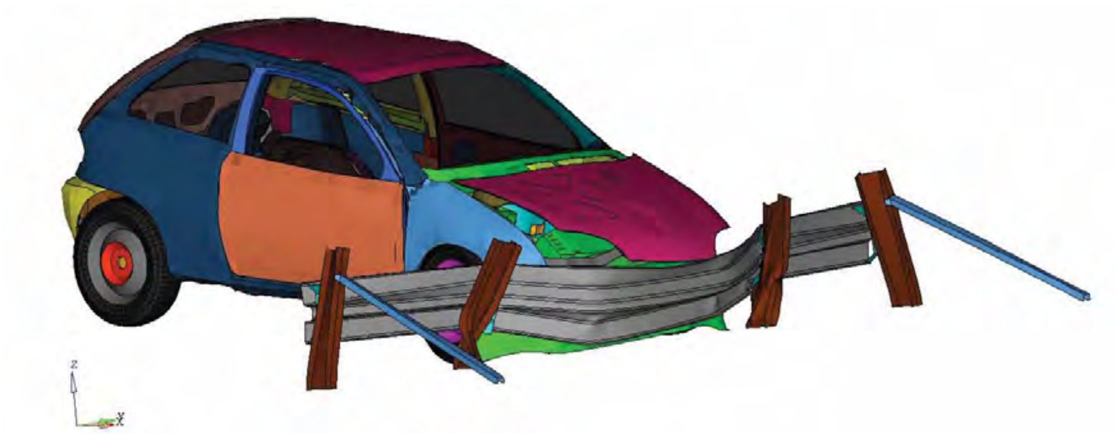

Fig. 13. Car-guardrail system at the instant t=0.3 s

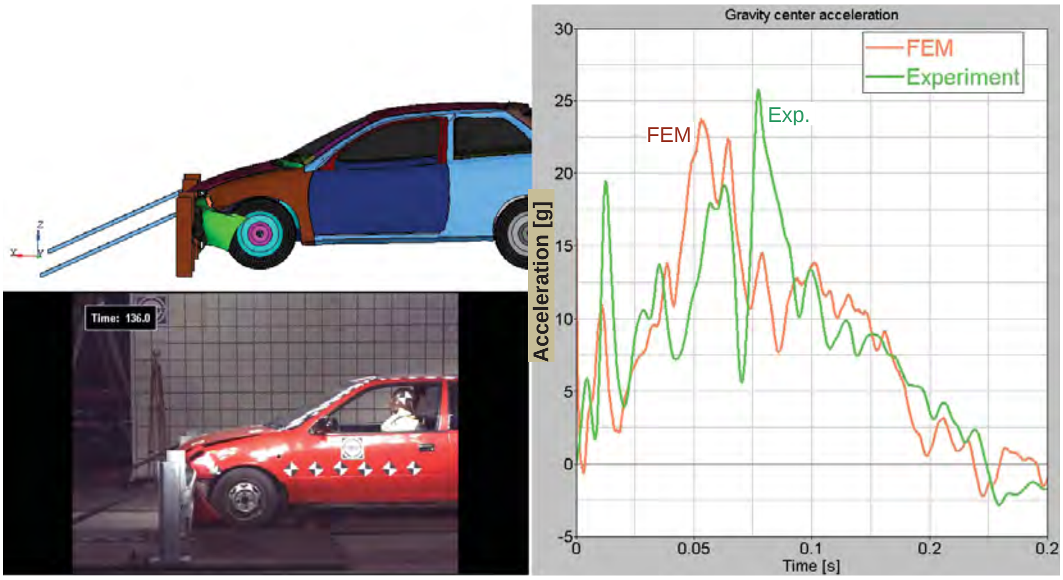

Fig. 14. Accelerations of the vehicle's centre of gravity. Comparison of the configuration of the C-G system at t he instant t=0.024 s

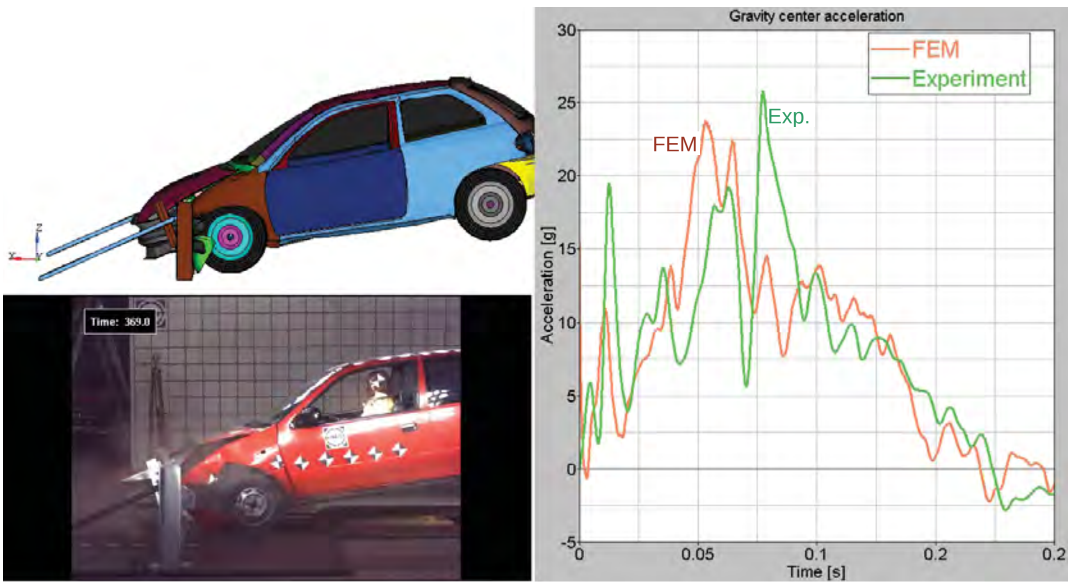

Fig. 15. Accelerations of the vehicle's centre of gravity. Comparison of the configuration of the C-G system at t he instant t=0.318 s

The calculated field of displacement and comparison of belt's deformations is presented in Fig. 16. The energy absorbed by the guardrail, as a result of plastic deformations, is computed by LS-DYNA system and equals to 23.7 kJ.

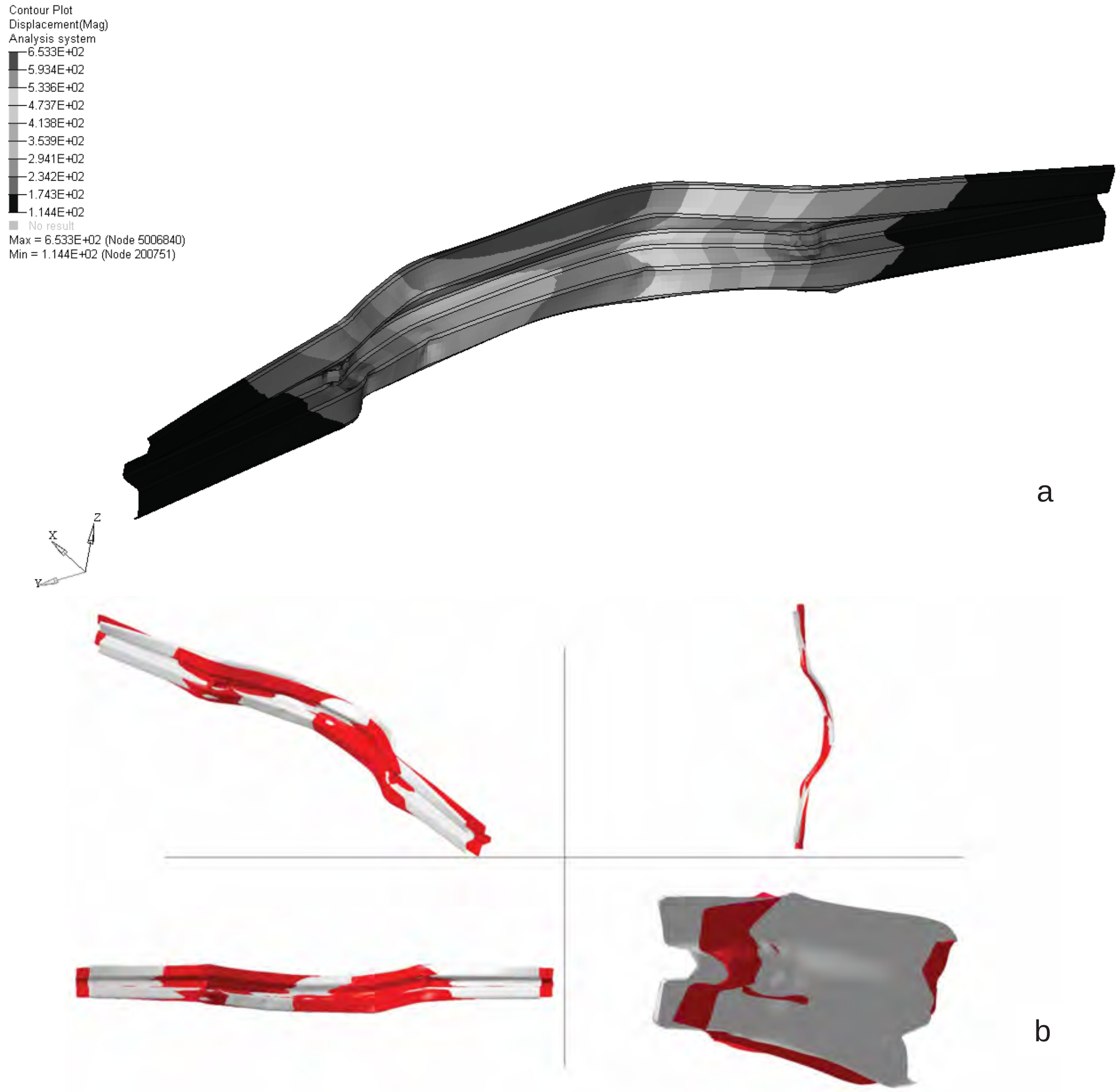

Fig. 16. Calculated field of displ acement (a) and comparison of the field of the belt defor mation, white - FEM , black - experiment (b)

5. Conclusions

In this work the conception and the results of the experimental validation of the numerical model of the system of the Suzuki Swift car and the B/IPE140 guardrail (marked with the code C-G) are presented. The conception of validation takes into consideration tests and simulation within the range of a basic load variant that is a vehicle's impact with the speed of 52.5 km/h at the angle of 90° without a braking process before the impact.

On the basis of the carried out experimental tests and the numerical simulation the following conclusions can be formulated:

1. The examination stand in the Vehicle Safety Laboratory of Automotive Industry Institute in Warsaw as well as the used measuring apparatus enabled carrying out the safe and well identified test of the crash type.

2. The process of an impact may be assessed as quasi-symmetrical. Deviations from symmetry are mainly caused by non-perfect constructional masses and non-uniform longitudinal flexibility of the frontal part of a vehicle.
3. The assumed initial-boundary and constructional conditions of the C-G system ensured an average destruction of the frontal part of the tested car as well as they enabled the manikin to survive.
4. The elaborated methodology of numerical modelling of the C-G system, utilizing advanced options of LS-DYNA system, ensured the reliable, spatial and experimental test of the crash type.
5. Very good qualitative conformity of the crash effect in numerical simulation with the experimental test was achieved. The similar stages of the process appeared in the numerical simulation as well as in the experimental test (Fig. 5).
6. The comparison of the time courses of acceleration acting on the vehicle centre of gravity which were achieved by the experimental and simulation ways, presents itself the basic validation test of the numerical model of the C-G system. It is known that differences between an experimental test and a simulation are the least in displacements and the biggest in accelerations. The good qualitative and quantitative conformities in accelerations were achieved. Differences are caused by non-perfect constructional masses and also by simplifications in the modelled connections.
7. The conformity of plastic deformation fields of the guardrail, achieved in the experimental test and in the simulation, is excellent (Fig. 16).
8. Results within the range of accelerations and plastic deformation fields enable the statement that the numerical model of the C-G system has been positively validated. It can be utilized in numerical tests of other systems, of C-G type, among others also to assign the absorbed energy by the subsystems subjected to plastic deformation.

References

[1] Niezgoda, T., Barnat, W., *Computational and Experimental Study of Energy Absorption Metter by Composite Structures,* Computional Methods In Engineering And Science Epmesc X, China Tsinghua University Press & Springer, Sanya 2006.

[2] Niezgoda, T., Barnat, W., *Analiza pasa bariery drogowej wzmocnionej elementami kompozytowymi w zastosowaniu do poprawy energoch łonności elementów infrastruktury,* Górnictwo Odkrywkowe Nr 5-6, 2006.

[3] Niezgoda, T., Barnat, W., Dziewulski, P., *Numeryczna analiza podatno ści elementów infrastruktury drogowej*, I Kongres Mechaniki Polskiej, Warszawa 2007.

[4] Niezgoda, T., Kiczko, A., Barnat, W., Dziewulski, P., *Validation of numerical models of road bariers elements with the use of experimental methods,* Symposium on Advances in Experimental Mechanics, DANUBIA-ADRIA, Romania 2007.

[5] Niezgoda, T., Barnat, W., Dziewulski, P., *Numeryczna analiza podatno ści elementów infrastruktury drogowej na przyk ładzie barier SP-01, SP-04 i SP-09*, Journal of KONES, Vol. 14, No. 3, 2007.

Acknowledgements

This study has been supported by the Ministry of Science & Higher Education of Poland as a part of the research & development project No R 10 001 01, realized within the period 2006-2009. This support is gratefully acknowledged.