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NUMERICAL MODELLING AND SIMULATION OF ROAD CRASH TESTS WITH THE USE OF ADVANCED CAD/CAE SYSTEMS

MODELOWANIE NUMERYCZNE I SYMULACJA DROGOWYCH TESTÓW ZDERZENIOWYCH Z WYKORZYSTANIEM ZAAWANSOWANYCH SYSTEMÓW CAD/CAE

Tadeusz Niezgoda, Wiesław Barnat, Paweł Dziewulski, Andrzej Kiczko

Military Academy of Technology, Faculty of Mechanical Engineering
e-mail: dziewul@poczta.fm; Andrzej.kiczko@wat.edu.pl

***Abstract**: The paper presents the methodology of numerical modelling of road crash tests based on the selected vehicle-road barrier system using the possibilities of modern CAD /CAE computing systems for a numerical simulation process of the collision. Owing to these systems, thorough analysis of the process of collision, including the analysis of the stress and strain fields and energy consumption in the tested systems, is possible. It is possible to design and redesign virtually the barriers at a relatively low cost.*

***Keywords:** crash, LS-DYNA, PN-EN 1317, finite element method.*

***Streszczenie:** W artykule przedstawiono metodykę modelowania numerycznego drogowych testów zderzeniowych na przykładzie wybranego układu pojazd-drogowa bariera ochronna, z wykorzystaniem możliwości nowoczesnych systemów obliczeniowych CAD/CAE do numerycznej symulacji przebiegu zderzeń. Dzięki wykorzystaniu tych systemów możliwa jest dogłębna analiza procesu zderzenia, w tym analiza pól naprężeń, odkształceń oraz energochłonności badanych układów. Możliwe jest wirtualne projektowanie i przeprojektowywanie barier przy relatywnie niskich kosztach.*

***Słowa kluczowe:** zderzenie, LS-DYNA, PN-EN 1317, metoda elementów skończonych*

1. Introduction

Development of modern computer-aided design systems, especially computational systems, provides practically unlimited possibilities within the range of simulating of complex physical phenomena. Body collisions, in particular vehicle collisions, with safety road barriers belong to these phenomena. In the paper, there is presented the methodology of numerical modelling of crash tests, taking as an example a chosen configuration of a vehicle-safety road barrier with the use of possibilities of modern counting systems, CAD/CAE, to simulate numerically crash runs.

2. Road infrastructure

Road barriers and energy consuming shields are implemented nowadays as active safeguards of road traffic the ones with which a vehicle comes into an immediate contact) [1].
According to the Decree of the Infrastructure Minister, issued on 3 July 2003, safety road barriers are the safeguards used to prevent a vehicle from pulling off the road or pulling off the other side of the road, or prevent a collision of a vehicle with the other objects or with the roadblocks which are placed nearby the roadway. Steel safety barriers are the most popular road safeguards.

3. Methods of road crash tests examination

Nowadays a real field crash examinations, according to PN-EN 1317, are used for road barriers. Numerical tests of safety road barriers can be helpful not only at the design stage (because of their speed, easiness, and price, as well as the possibility of investigating many variants simultaneously, introducing modifications or testing new solutions, physically not existing yet solutions) however, as it is proved by many authors, they can serve to carry out reliable, numerical (virtual) crash tests. This approach has the only advantages, the most important of which are speed and the low cost of numerical tests. For example, in work [2] there is described the numerical analysis of the Geo Metro car impact into a safety road barrier and the experimental validation. A new solution, which consists in using a different separator between a strip and a post, has been proposed. In work [3] new constructional solutions of safety road barriers are also proposed. The aim of these solutions is not to increase energy-consumption possibilities of barriers but to reinforce the existing solutions to manage the TB42 test, that is the impact of the 10 t truck. In work [4] there is considered a problem connected with the numerical simulation of the impact of the HYBRID III manikin with a safety road barrier. Individual cases were numerically analysed for a model of the real SP-05 barrier with additional constructional changes which improve the safety of road users. An influence of the barrier modification on a car behaviour at the crash has been also investigated. In the aforementioned works, the wide implementation of numerical methods and their compatibility with real tests takes place. Hence, introducing numerical methods as equal to experimental ones, in this subject, seems to be substantially and economically justified.

4. Methodology of numerical modelling of road crash tests

The range of works comprises experimental and numerical tests of chosen elements of a road infrastructure as an example of the methodology of numerical modelling of road crash tests worked out in the Department of Mechanics and Applied Computer Science. Evaluation of the safety road barriers is to be carried out experimentally as well as numerically where reliable models, basing on experimental results, are to be used.

The worked out methods of numerical analysis for different crash cases will contribute to lowering costs and time of stand tests of real objects. The proposed methodology of the modelling of road crash tests of existing safety barriers is to be a point of departure for range investigation, since the base of adjudication of the barrier quality is a crash test performed according to the PN-EN 1317 European standard.

On the roads, the only barriers which can be admitted are those which proved their effectiveness at crash tests and are, in every aspect (physical, technical and technological), identical to those subjected to the crash tests.

The range of the work comprises the following research works concerning a configuration of a vehicle-safety road barrier.

- Carrying out experimental, identifying tests for numerical modelling materials and a process of collision
- experimental validation of a numerical model of a configuration
- modelling and numerical simulations of a collision process according to PN-EN 1317.

Experimental identifying research directed to determine material constants for constitutive models

In the experimental part, there is carried out an identifying material investigation, comprising tests, e.g. stretching, squeezing, static shearing of samples, depending on a tested material (steel, foamed polyurethane, foamed aluminium, composite). Strength tests are indispensable to determine fundamental material constants in constitutive compounds.

Presented in Fig. 1 samples have been cut out from two cross-sections of a guide, 5 samples from each cross-section. As it is known, the guide material, because of rolling, is characterized by the orthotropic properties, so that is the reason of cutting out samples from the longitudinal direction.

During a vehicle impact into a barrier, a guide is stretched and bended, which leads to appearing stretching and squeezing stresses at the longitudinal direction.

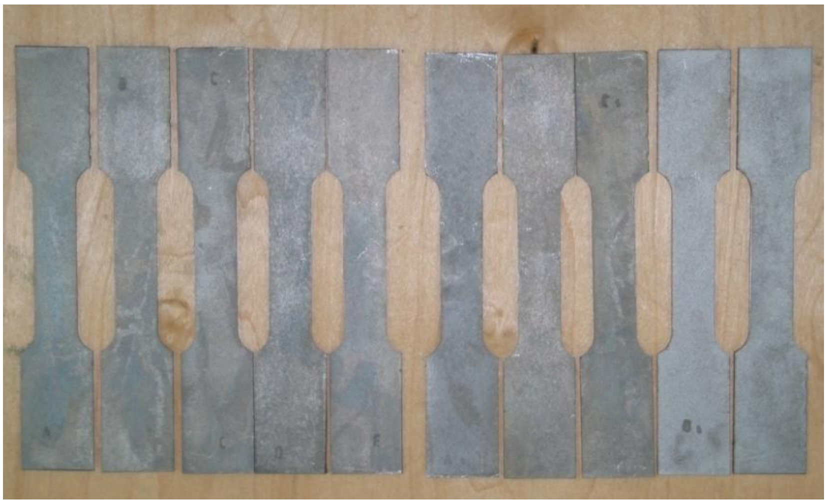

Fig.1. Samples for static stretching tests

In Fig. 2, the stretching curve for an exemplary, tested sample is presented.

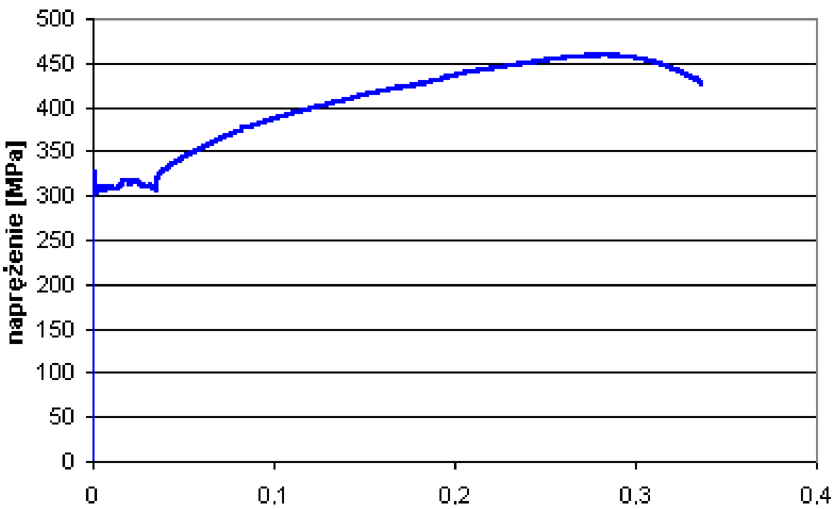

Fig. 2. Course of static stretching test

For the needs of the description of constitutive models, applied in the counting system, used to the analysis, there has appeared the necessity of changing stresses in a function of strains as an engineering measure, received from the strength machine, Instron, on real stresses (logarithmic) and real strains (Fig. 3).

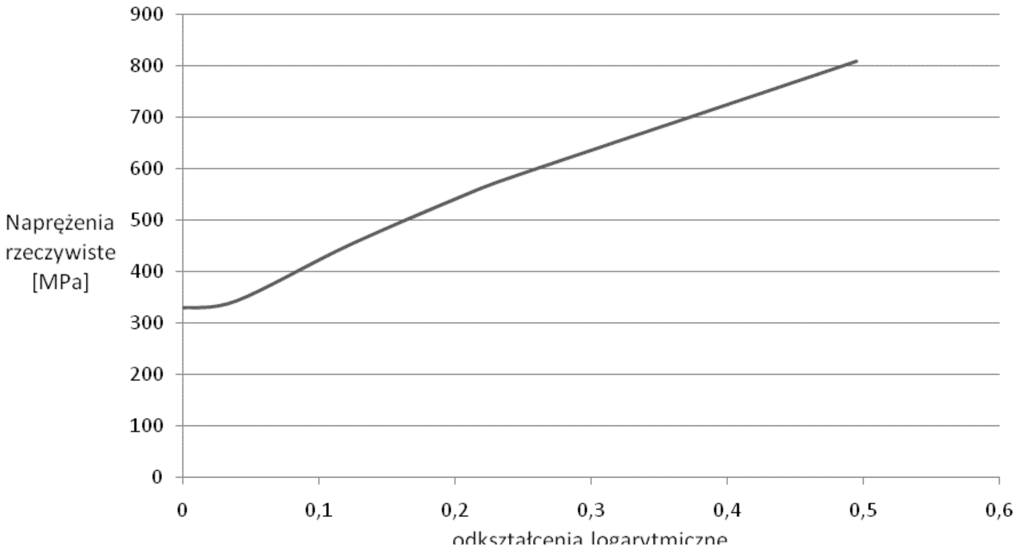

Fig.3. Real stresses as a function of real strains (logarithmic).

As the test result, the data for the elastic-plastic material model of a safety road barrier elements have been obtained.

4. Experimental validation of numerical models

Numerical model of a fragment of the safety road barrier

The construction of reliable numerical models is the next stage. Numerical models of safety road barriers have been constructed on the basis of technical drawings, placed by one of the producers of barriers - the Stalprodukt firm.
The first stage was creating a surface geometric model of the analysed barrier fragment. In Fig. 4, an exemplary model of the SP-01 barrier fragment is depicted.
As it is known, a real structure has a considerable thickness, hence, taking into account later MES analyses with the use of surface elements, a model resting on a middle surface should be created.
The next stage is the division of a surface geometric model into finite elements and giving them physical properties through defining materials, thickness and joints between individual parts of a barrier (Fig. 5).
In order to describe the numerical model of safety road barriers, the model of an isotropic material with the elastic-plastic reinforcement has been used.

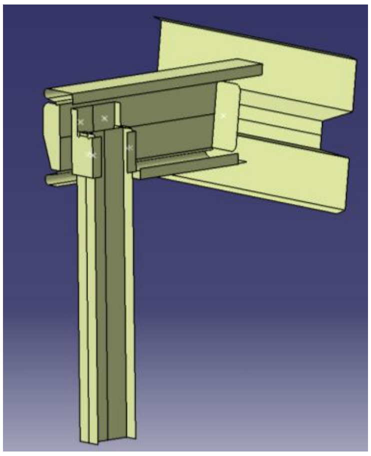

Fig. 4. Geometric model of a fragment of the SP-01 road barrier

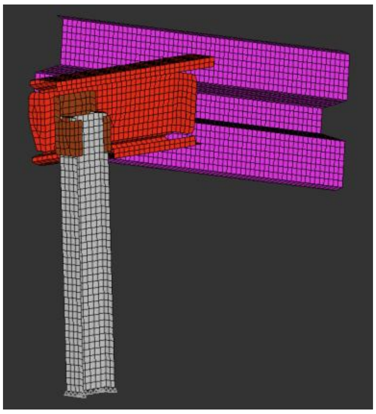

Fig. 5. A model divided into finite elements of the fragment of the SP-01 road barrier

The joint of the *CONSTRAINED_SPOTWELD type with a failure has been used to join elements of a barrier. After exceeding a destructive value of the tensile force and/or the shearing force of a joint the rupture of a joint takes place. After initial simulations, it appears that using a joint subjected to destruction is a necessity in order to prevent non-physical behaviour of a striking vehicle.

Numerical analysis of static bending of road posts with fragments of barriers and a guide, and comparison of results with experimental tests

The aim of this stage is to test the way of deformation of a single post and a guide at the static loadings and then comparison of the results with experimental tests.

The models have been subjected to the transverse bend test, loading with a non-deformed stamp, moving at constant speed. Calculation is performed in the LS-DYNA system [5]. The way of the model deformation is similar to the way of deformation of real systems (Fig. 6).

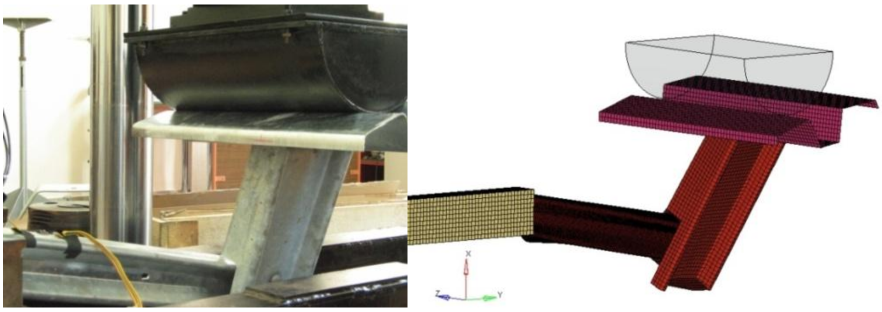

Fig. 6. Comparison of the final form of the real construction deformation and its numerical model

A good compatibility of dependence "force-displacement" in experimental tests and a simulation have been achieved (Fig. 7).

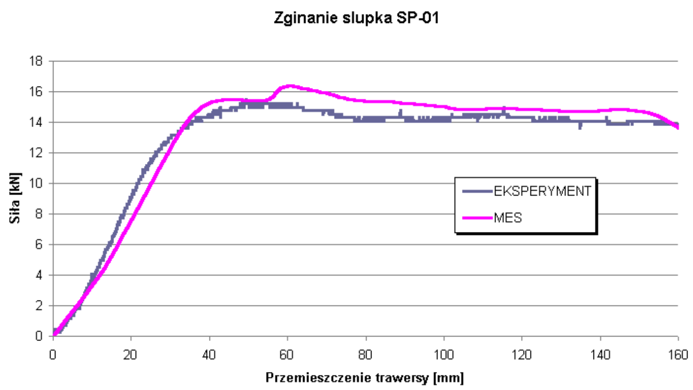

Fig. 7. Comparison of curves loading force–displacement of a traverse in the process of bending of a post and the SP-01 barrier received in experimental tests and simulation

Numerical analysis of bending of a road post with the fragment of the SP-01 barrier

The run of the numerical simulation of bending of the roadway guide at a traversal approach angle of 20°is presented in Fig. 8, depicting the model deformation at the traverse movement: 0 and 400 mm, respectively.

Fig. 8. Comparison of deformation of the real construction and its numerical model

The way of deformation of a model is similar to the way of deformation of a real construction. Bending of a strip in the place of fixing a stamp has occurred both in the real construction and in the numerical model. After introducing the substitute flexibility of supports, the compatibility of a dependence force-displacement in real and numerical tests has been achieved (Fig. 9).

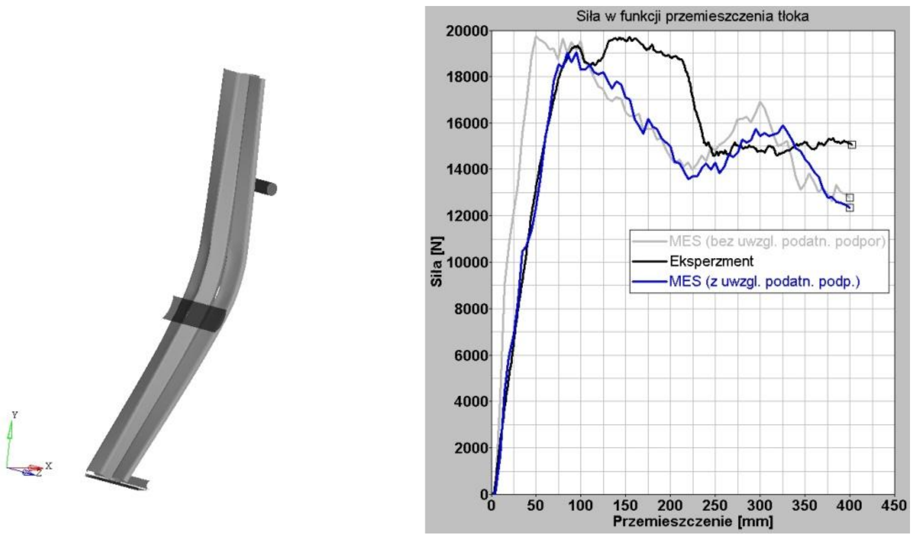

Fig. 9. Comparison of loading force–displacement curves of a traverse in tests and numerical simulation MES (at a traversal approach angle of 20°)

5. Validation of models simulating crash tests of a car with a barrier

Numerical model of a stand

Experimental and constructional initial-boundary conditions have been taken into account in numerical simulations. The numerical model consists of the Suzuki Swift car [6] and a fragment of a road barrier together with IPE 140 bridge posts (Fig. 10).

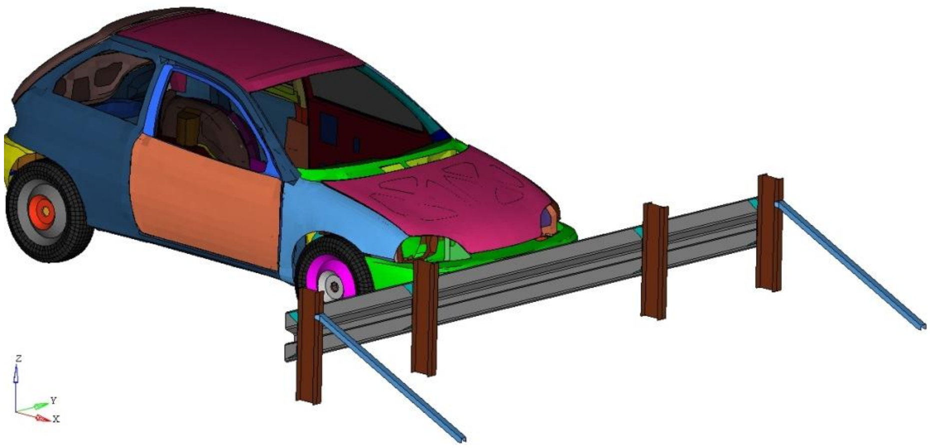

Fig. 10. A general view of a model

The model of a fragment of a modified barrier comprises 12 000 elements of a surface type. The model takes into account destruction of a material, and destruction of elements joining posts with a guide.
A phenomenon of contact has been taken into account while carrying out the analysis. The contact is realized through introducing additional elements transmitting loading. This phenomenon is realized in the LS-DYNA system through a contact of a node-surface type [5], enabling modelling mutual interactions between a few parts or one body in the case of a self-contact, frequently appearing at large displacements and deformations. Its main aim is to eliminate all penetration between surfaces through applying forces balancing penetration. The applied model of cooperation of two objects is based on an analysis of physical values using the penalty method. During the analysis, gravitational loading is realized in order to ensure the real behaviour of a vehicle and a barrier during the time when the phenomenon occurs.
Gravitational loading is realized at the initial phase just before an impact into a barrier with the help of *DYNAMIC_RELAXATION card. Such an attitude eliminates arising instabilities at violent loading of models.
Reaction of vehicle wheels with a base has been taken into consideration as well.
The coefficient of static and kinetic friction “tyre- asphalt” has been assumed as equal to 0.8.

Results of experimental tests and numerical analysis

The results obtained from the analysis of the system deformation and accelerations in a function of time of the vehicle centre of gravity are depicted in Fig. 11. In an analysed example, a car hit into a barrier at an angle of 90 ° with the initial speed equal to 52.5 km/h.

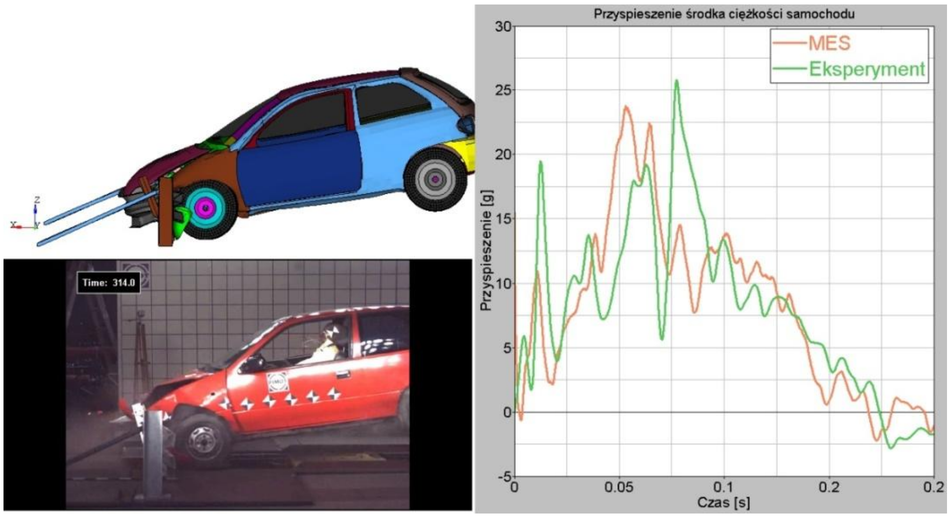

Fig. 11. Comparison of deformations and accelerations, operating in the vehicle centre of gravity for a fragment of a road safety barrier without any energy-consuming panels

In a numerical simulation, the stages are identical to those from the experiment: impact, impact into a barrier strip, plastic deformations of a barrier and a frontal part of a car, lifting of the back part of a car, rebound from a barrier, dropping back wheels on a platform.

To evaluate the correctness of received results, which are in a form of diagrams of acceleration in a function of time, the Roadside Safety Verification and Validation Program (RSVVP) has been used, which calculates parameters of comparison of curves (differences between them) in order to check and validate phenomena such as a collision.

Comparison of the received parameters, calculated with the use of RSVVP according to ANOVA (analysis of variance) and Sprague&Geers MPC (magnitude phase composite) algorithms may be used for checking numerical simulation models on the basis of the received experimental tests, verification of simulation results, comparison with other simulations or analytical solutions, repeatability evaluation of a physical experiment or, generally speaking, practically it can be a comparison of each pair of curves. Comparison of accelerations is presented in Fig.12.

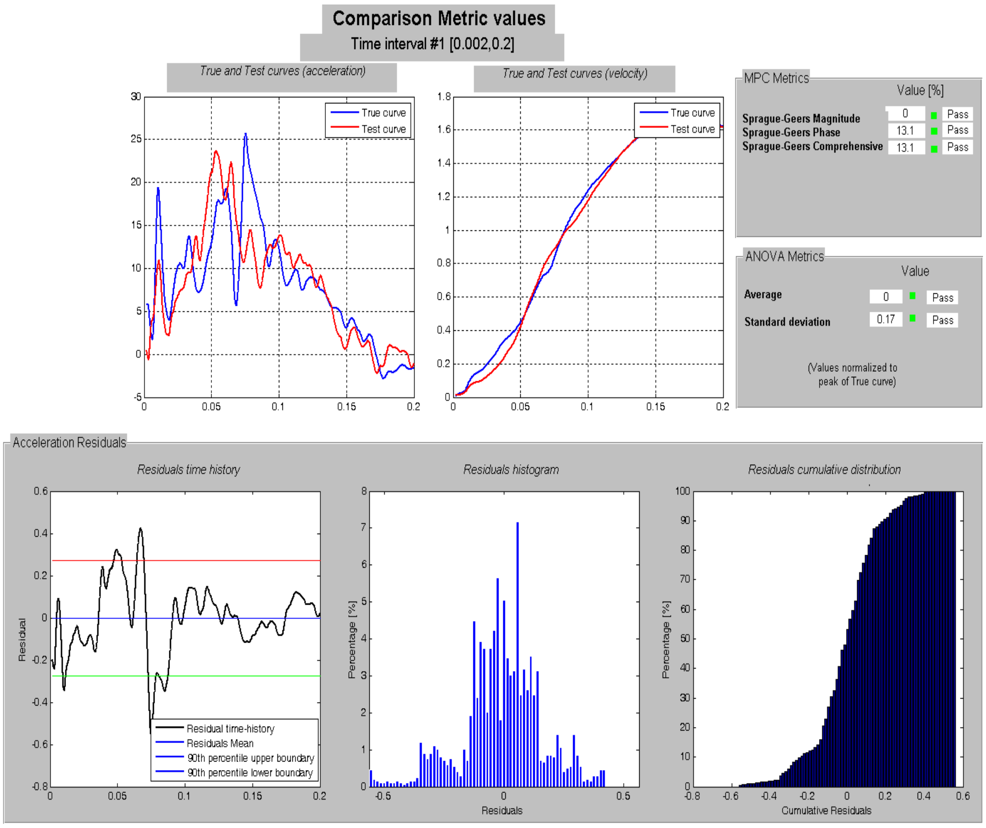

Fig. 12. Validation of results with the use of RSVVP programme

Comparison of time runs of acceleration acting on the centre of gravity of a vehicle, received experimentally and by a simulation, is the fundamental validation test of a numerical model of a-“car –road safety barrier” configuration. As it is known, differences between an experiment and a simulation are the smallest in displacements, and the biggest in accelerations.

In accelerations, the very good quality and quantity compatibility has been achieved. Differences are caused by constructional and mass imperfections and by simplifications in modelling joints.

Using of the Handyscan laser scanner enabled comparison of the deformed guide, from the experimental test, with a guide from the numerical simulation.

The shape of the deformed guide from a real impact has been reconstructed and then compared with deformations of a guide received from the numerical analysis. The results are presented in Fig. 13.

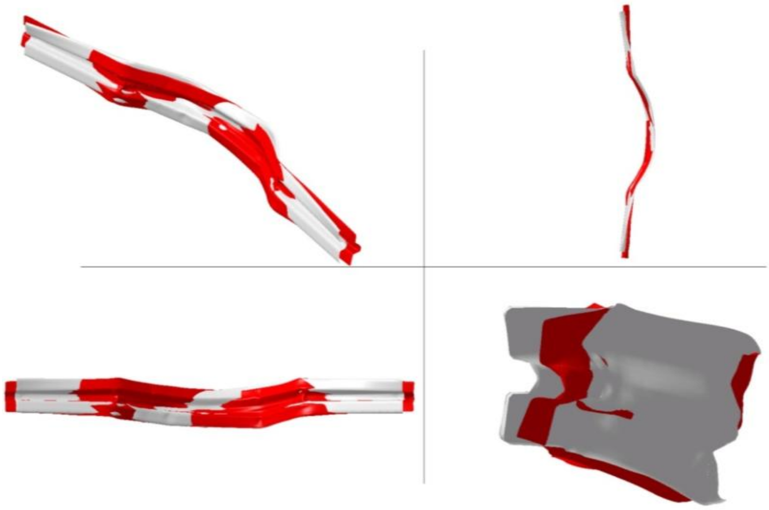

Fig. 13. Comparison of a plastic deformation field of a strip.
White – MES, red – experiment

A very good compatibility of plastic deformation fields of a road safety barrier strip has been achieved both in an experiment and in a simulation.

6. Modelling and numerical simulation of collision process according to PN-EN 1317

At this stage, owing to the earlier presented approach, it is possible to perform numerically a lot of variants of crash tests according to PN-EN 1317. Lots of numerical crash tests, which were carried out in the Department of Mechanics and Applied Computer Science, used various types of vehicles which had collisions with road safety barriers, confirm rightness of the chosen methodology.

As an example, the TB11 test is given, in which a striking car with the mass of 900kg moves at speed of 100 km/h, at an angle of 20° to a barrier.

A fragment of the SP-06 barrier, 60-meter long, with posts located every 1m has been modelled (Fig.14). An influence of locating the kerbs on the run of an impact and the coefficient of intensity of the ASI acceleration have been tested.

The exemplary results compared with the data from catalogues of the firm Stalprodukt [7] are presented in Table 1.

Tab.1. ASI results for numerical and experimental simulations.

	max ASI MES	**max ASI Stalprodukt (badanie poligonowe)**
TB11 without a kerb	1.2	1.2
TB11 with a kerb (minimal distance)	1.3	
TB11 with a kerb (staging distance)	1.4	
TB11 with a kerb (maximal distance)	1.4	1.3

Fig. 14. A general view of a „car-road barrier"configuration

7. Conclusions

The elaborated methodology of numerical modelling of systems, using the advanced options of the LS-DYNA system, enables getting reliable, spatial simulation of the experimental test of the collision phenomenon.
A very good quality compatibility of the collision phenomenon is achieved as a result of the numerical simulation and the experimental test.
The results within the range of accelerations and fields of plastic deformation allow a statement that a numerical model of the "car – road safety bar" configuration has been built correctly and for the assumed assumptions appropriately reflects the analysed collision process. It can be used in numerical tests of other configurations of "car – road safety bar" type.

8. Literature

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[6] http://www.ncac.gwu.edu
[7] http://www.stalprodukt.com.pl/

Prof. Tadeusz Niezgoda, *Wojskowej Akademii Technicznej, kierownik Katedry Mechaniki i Informatyki Stosowanej na Wydziale Mechanicznym. Jest specjalistą z dziedziny komputerowej mechaniki konstrukcji. Autor metody numerycznej analizy różnych klas konstrukcji, w szczególności w warunkach obciążeń ekstremalnych, m.in. uderzenie pociskiem i wybuch miny, z zastosowaniem zaawansowanych systemów CAD/CAM/CAE. Jest autorem bądź współautorem ponad 300 artykułów naukowych oraz 3 monografii. Wyróżniony nagrodą Ministra Obrony Narodowej za całokształt dorobku, a zespół pod jego kierownictwem otrzymał nagrodę Ministerstwa Infrastruktury za innowacyjne rozwiązania z obszaru bezpieczeństwa uczestników ruchu drogowego i opracowanie transportu intermodalnego.*

Dr hab. inz Wiesław Barnat, prof. WAT, *Pełnomocnik Szefa Katedry ds. Strategii Projektowej Katedry Mechaniki i Informatyki Stosowanej Wydziału Wojskowej Akademii Technicznej. Zajmuje się zagadnieniami numerycznej analizy zjawisk szybkozmiennych w aspekcie: rozpraszania energii udaru lub wybuchu, przebijalności (nożo i igło odporności), oddziaływania sprzężonego zjawiska odłamka i wybuchu na osłony m.in. kompozytowe, oporów pływania pojazdów pływających, crasch testów i odpowiedzi konstrukcji pojazdów wojskowych na strzał z broni pokładowej dużego kalibru.*

Dr inż. Paweł Dziewulski, *specjalista naukowo-techniczny w Katedrze Mechaniki i Informatyki Stosowanej Wydziału Mechanicznego WAT. Zajmuje się numerycznym modelowaniem złożonych zjawisk fizycznych w szczególności symulacjami zderzeń.*

Dr n.t. Andrzej Kiczko, *starszy wykładowca w Katedrze Mechaniki i Informatyki Stosowanej, Wydziału Mechanicznego WAT. Specjalizuje się w metodach eksperymentalnych mechaniki. Zajmuje się badaniem materiałów i konstrukcji przy obciążeniach statycznych i udarowych.*