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IDENTIFICATION OF THE PARAMETERS OF VEHICLE CONTACT WITH A RIGID BARRIER FROM A CRASH TEST

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Abstract: *This article presents both the results of computer simulations of vehicle crashes with a rigid barrier, simulated with the V-SIM simulation software, as well as the experimental results published by ADAC (Allgemeiner Deutscher Automobil-Club). The results were obtained for the same initial conditions, which provide an opportunity to evaluate the computer simulation's credibility and the identification of selected parameters; wheel blocking time, car body stiffness and the coefficients of friction and restitution. Once those parameters have been changed, a good agreement with experimental results was reported. The remaining difference is a result of a simplified modelling of forces which act during a vehicle collision. All that shows that expert witnesses should provide, in their expertise, a range of parameters for which they receive a similar accident reconstruction and not to base it on a single simulation only. They should do it due to input data uncertainty, and the sensitivity of the accident reconstruction to input data.*

Keywords: V-SIM, Crash model, Parameter identification, Sensitivity, Contact.

1. Introduction

Today's road accidents are reconstructed by expert witnesses, being commissioned by the bodies involved in a court case with the use of computer software, which generates specific consequences for the parties to the court proceedings. The models applied in such programs are simplified, which introduces errors into the results of the calculations. Similarly, the default values of the parameters do not always correspond to the real values of parameters which occurred during the crash. It refers to e.g. the body stiffness and friction coefficients (McHenry et al., 1997, Rose et. al., 2006). All that does is to introduce some uncertainty of the calculations, which is additionally increased by the sensitivity of the accident reconstruction to the input values of the given parameters, which is typical for the systems with body contact (Kostek, 2014, Kostek, 2012). Expert witnesses are not, unfortunately, aware of those phenomena and so they approach the results without any reservations. Accident simulation and reconstruction are thus an important issue, with both cognitive and practical qualities (Aleksandrowicz, 2016, Bułka et al., 2006 and Wolak, 2011). This article focuses on the identification of said parameters, e.g. wheel blocking time, parameters of the contact of the car body with the barrier and the coefficient of friction between the tire and the "road surface", as well as the effect of those parameters on the accident pattern. Expert witnesses use the software which performs calculations in MBS (Multi Body System) convention on a PC (http://www.cyborgidea.com.pl, http://www.pc-crash.com, http://www.vcrashusa.com). Such calculations are burdened with some errors due to constant mass parameters of the vehicle during a crash; a linear dependence between the vehicle deformation and the contact force, as well as uncertain input data affecting the result of the accident reconstruction (Wach et al., 2007a and Wach et al., 2007b). In Poland, expert witnesses commonly use V-SIM software which models crashes in the MBS convention (http://www.cyborgidea.com.pl). In literature known to the authors, the errors of simulation obtained with V-SIM for head-on collisions were not investigated, hence the study of this issue in this article.

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2. Crash investigation

The V-SIM software applies two co-ordinate systems, the global one related to ground *xyz* and the local one *x'*, *y'*, *z'* related to the car body (Figs. 1a, 2e). Crash test involved a Renault Twingo manufactured before July 1993. For the purpose of the calculations, the following data were applied: a vehicle from V-SIM database (VSIM4.0 – User manual, 2016) and 845 kg as vehicle's curb weight, the driver and passenger weights – 68 kg, 155/65 R14 tires and tire model TM – Easy, 2.247 m wheelbase, and wheel tracks – 1.416 m for the front axle and 1.374 m for the rear axle, respectively. The vehicle's initial velocity was 50 km/h.

The experiment was started from the modelling of a barrier which consists of a cuboidal block and a round pillar. Then the vehicle was positioned in a way so as to receive a 40 % (0.65 m) overlap, as declared by ADAC (Brieter, 1993, https://www.youtube.com/watch?v=UoaI-NuGBN4). In the next step, there were matched to the images recorded by a camera which filmed the collision from the top. Time $t = 0$ ms was assumed for the moment of the initiation of the contact between the vehicle and the barrier (Fig. 1b). For that film frame the vehicle scale was adjusted. Then the vehicle was slowed down and for $t = 100$ ms there was observed large body deformation and a decrease in the vehicle's speed. The images received for $t = 100$ ms look similar (Fig. 1c, 1d).

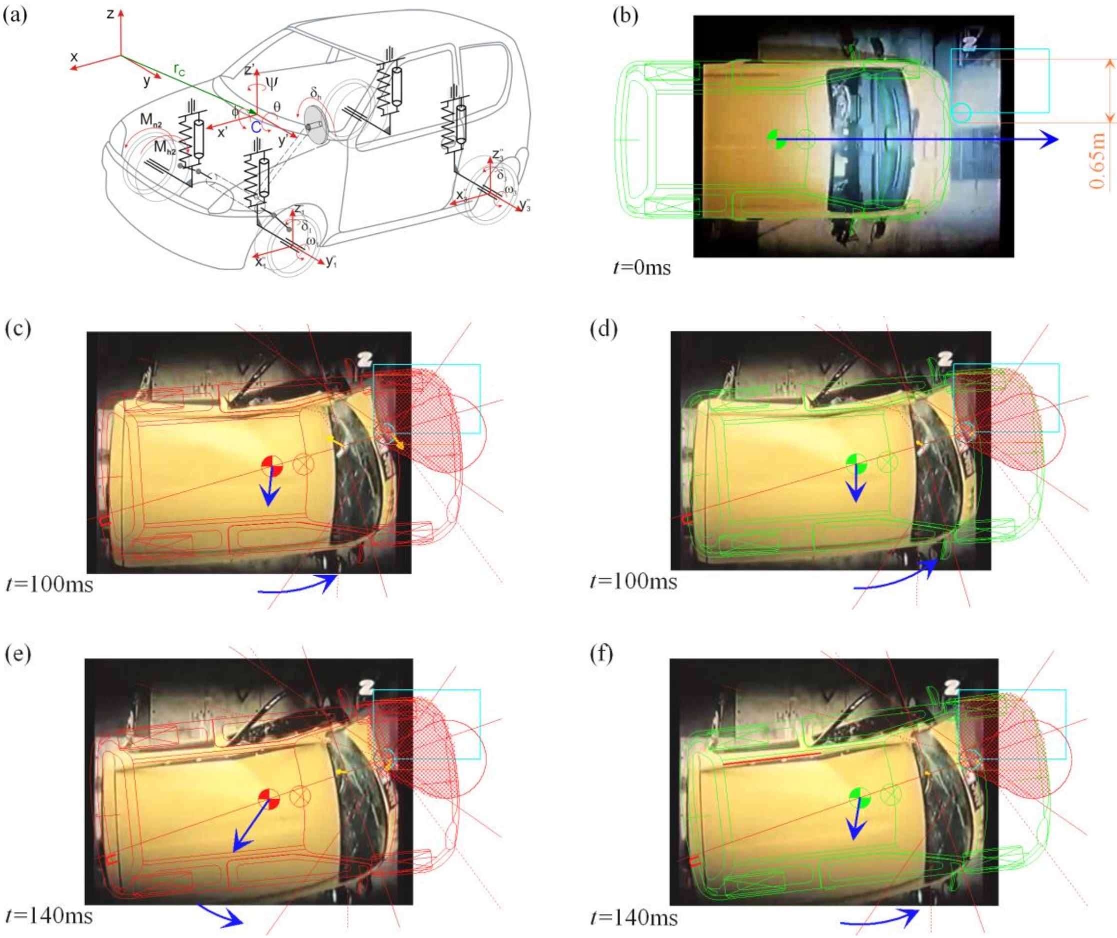

Fig. 1: a) Vehicle model and co-ordinate systems; as well as a comparison of the experimental results with the simulation results – default (b, c, e) and changed (b, d, f) input data.

Then the vehicle bounces and turns ($t = 140$ ms). In this case the speeds and positions received for the two simulations differ clearly. For the modified parameters, the rotation of the vehicle is larger, which reflects better post-impact movement. The red line marks the left edge of the roof to demonstrate a good agreement between the angles of rotation (Fig. 1f).

The next stage involved a comparison of the time histories obtained for the default model, the model with modified parameters and a presentation of experimental results measured from the images recorded. The measurements were made by reading the position of selected points on a bitmap. In this case the base was provided by the back and white scale for $t = 0$ ms and non-deformed part of the vehicle right behind the vechicle door. And then a correction was introduced for the rotation of the vehicle based on simulation results. Performing the series of iterations, a satisfactory agreement between the results was received (Fig. 1f, 2e).

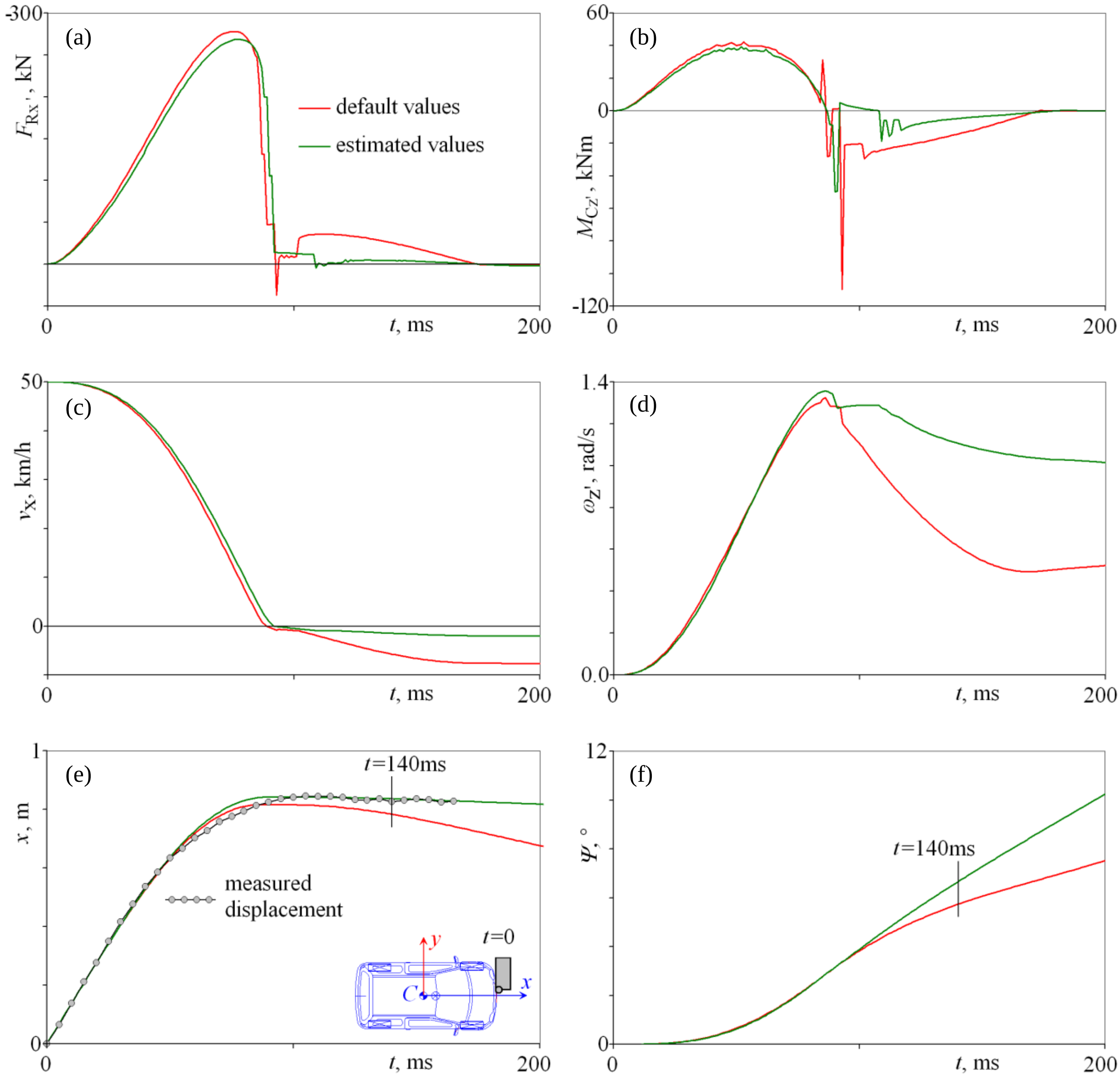

Fig. 2: Time histories of: a) projection on axis x' of resultant force F acting on the vehicle; b) component of resultant moment acting on vehicle $M_{Cz'}$; c) linear velocity $v_{x'}$; d) angular velocity $\omega_{z'}$; e) displacement of the center of mass of the vehicle in the global system x_c; f) angle of rotation ψ.

The identification resulted in the following changes of parameters: the coefficient of body stiffness for the compression phase was decreased from 414 kN/m^3 to 378 kN/m^3, and for the restitution phase – it was decreased from 414 kN/m^3 to 300 kN/m^3, the coefficient of restitution was decreased from about 0.25 to 0.08. Additionally, the left front wheel was blocked for t = 32 ms. The coefficient of friction between the tyre and the ground was decreased to 0.5 due to a loss of contact between the back wheels and the "road surface", both for static and kinetic friction. A decrease in the coefficient of stiffness at the compression phase allowed for matching the body deformation, whereas the other parameters helped to match the rotation of the body. As a result, the greatest differences between the results are visible for the restitution phase.

3. Conclusions

The study shows a satisfactory agreement between the experimental results and the results of the simulation only after introducing changes in the value of the parameters and wheel blocking. There was received a similar accident reconstruction, a similar body deformation and a similar angle of rotation for t = 140 ms. A growing difference between the results at a later simulation phase comes from sensitivity to input parameters; stiffness and coefficient of restitution, friction coefficient. Another pattern is found for the forces and, as a result the vehicle bounces off the barrier differently and velocity vectors have a different direction and module. As a result, another post-accident position is obtained. Such effect is typical for non-linear systems and it is referred to as a butterfly effect. Simulation in the mode of default parameters offered by the program generated worse results, which confirms an essential role of experts and their experience. Additionally, instead of the application of simple contact models, one should use the characteristics received in FEM (Finite Element Method) or experimentally. Such a solution would not cause any doubt, and, at the same time, the computational costs would be low. Another solution would involve a simplified or partial vehicle modelling in FEM. For example a deformed part of the vehicle could be modelled in FEM and the rest – in MBS convention. The study demonstrates a sensitivity of the results to selected parameters, which is typical for non-linear systems. Bearing that in mind, a practical conclusion can be developed: each accident reconstruction simulation software should also include an optimizing module facilitating the identification of initial conditions and the accident reconstruction.

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