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SELECTED PROBLEMS OF MODELLING OF VEHICLE COLLISION WITH A POLE

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Abstract: *Road accidents and collisions are negative effects of automotive development. Should there be no possibility of identifying the offender at the scene, experts are appointed to perform the investigation. To reconstruct a collision, the experts use simulation programs and the expertise developed when applying the programs affects the outcome of court proceedings. Currently the analytical calculations have been replaced with computer programs the results of which the experts usually consider valid. The article investigates a problem of the simulation program generating different results for the same incident. The results can be used by researchers modelling the collisions of vehicles, vehicles with elements of road infrastructure and with pedestrians; the results are also used in applications.*

Keywords: uncertainty in reconstruction vehicle collision, collision modelling, crash model

1. Introduction

A number of vehicles in the countries of the European Union keeps on growing, which enhances the economic development. However, the development also brings threats in a form of an increased road traffic intensity. The major negative effects are road accidents and collisions the reconstruction of which is currently performed with simulation programs. Applying advanced computer programs, which definitely include simulation programs, for vehicle collisions analysis, poses threats which result from a hardly critical acceptance of the numerical results as valid. Th experts should consider the limitations of collision modelling which simplifies the phenomena. The problem of modelling uncertainty for the crash and for the vehicle motion after the crash occurs when the model of a given physical phenomenon generates different computer simulation results.

Collisions can be simulated following the Finite Element Method (FEM) as discussed, e.g., by Mohsen et al. (2023). The programs which use FEM are most often applied by research institutions and vehicle manufacturers. Despite a possibility of performing precise calculations with FEM programs, in fact, in accident reconstruction they are not found. The calculations to be made while applying such programs is very time consuming and it requires the input of a number of material and geometrical data. The availability of numerical car models for impact simulation is also limited. Therefore, in their practice, court experts apply programs modelling the crash in a simpler way. Those programs involve the impact models which assume approximate linear dependences between vehicle body deformation and contact force. The problems of modelling vehicles and their motion as well as crashes have been discussed, e.g., in other papers (Aleksandrowicz, 2018a, b; Kostek et al., 2017), whereas contact with an obstacle can be detected in a 2 or 3D space, which has been used in this study.

2. Research tools and methods

For modelling a passenger car crashing into a pole, there has been applied a simulation program used for road accident reconstruction; V-SIM version 6.0.21, and two collision detection models offered by that IT tool. Simulating vehicles’ collisions with obstacles in V-SIM program is possible with a force model where

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the forces acting between the participants develop continuously from the contact moment to the moment the vehicles get separated and the impulsive model where the exchange of the force impulses between vehicles during the crash occurs within a single moment. For the purpose of this study, the impact force model has been used. The vehicle motion is described in two frames of reference. The global one which describes a momentary position of the car simulated and the impact elements distribution, including the obstacles. The coordinate system axes are x, y, z, whereas the axes of the coordinate system related with the car simulated – x', y', z'. Radius vector R_c determines the position of the centre of mass of the car. Figure 1 presents a vehicle model with the frame of reference applied in the program.

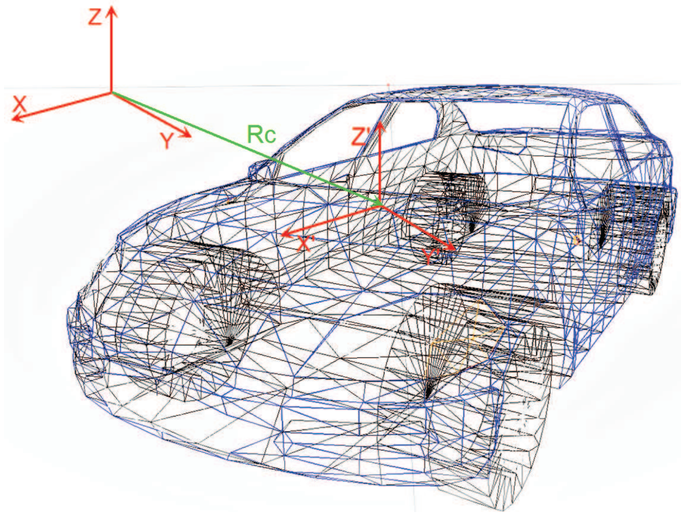


Fig. 1: Vehicle model with a frame of reference in V-SIM.

A four-wheel vehicle moves in the simulation program in a 3D space, and the vehicle has ten degrees of freedom. The car model has considered the suspension system rigidity and the steering system. Besides, the car model makes it possible for the operator to change the body rigidity at the compression and restitution phase and to manually enter the phrases: locking the wheel, wheel displacement, as well as flat tyre, car acceleration and braking. The car model also allows the operator to consider the load and its position in the car. Loads transport problems are discussed, e.g., in another paper (Fomin et al., 2020). In V-SIM the operator can choose from two detection models for a car collision with an obstacle: 2D and 3D. The 2D model detects the contact from the occurrence of overlap of the simulation objects in the projection of their silhouettes on the ground. The 2D model car collision detection is demonstrated in Figure 2a. The 3D model uses a three-dimensional map of points of the car interior and contact is identified by checking the penetration of a 3D car grid and the obstacle. The 3D model car collision detection is shown in Fig. 2b.

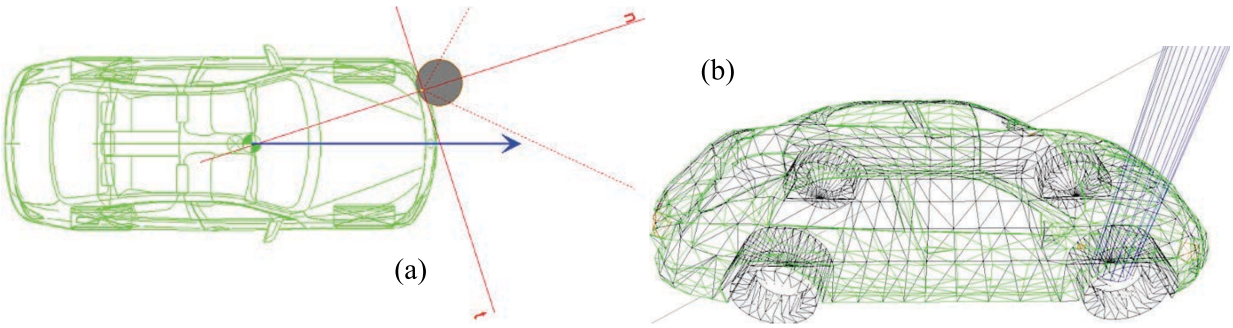


Fig. 2: 2D collision detection model (a) and 3D collision detection model (b).

3. Vehicle data and impact parameters

The vehicles' technical data and impact parameters as well as the obstacles assumed in the simulation calculations are presented in Table 1. The impact simulation has involved a numerical model of a BMW car series 3, sedan 320d xDrive A/T8 and a non-deformable pole 0.508 m in diameter.

Tab. 1: Technical data of the vehicle and of the obstacle as well as impact parameters.

Parameter	Value
Driver's weight	65 kg
Vehicle curb weight	1520 kg
Vehicle length/ width / height	4.624 m / 1.811 m / 1.429 m
Vehicle wheelbase	2.540 m
Track front axle / rear axle	1.543 m / 1.583 m
Tires front axle / rear axle	225/40 R19 / 245/40 R19
Inertia moments in x, y, z system	580/2622/2755 kgm^2
Body rigidity coefficient	745 kNm^{-3}
Pole rigidity coefficient	200 MNm^{-3}
Pole height / diameter	5.000 m / 0.508 m
Surface type asphalt	Adhesive friction coefficient μ_a=0.8 Slip friction coefficient μ_s=0.75
Rolling resistance coefficient	0.015

4. Case study – own research

The BMW car moving at 50 km/h crashing into a pole was simulated first in the 2D collision detection model and then in the 3D model. The BMW's initial position in the simulations was assumed as t=0.000s. For the car in such initial position, see Fig. 3.

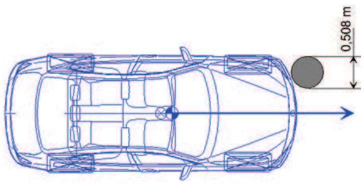
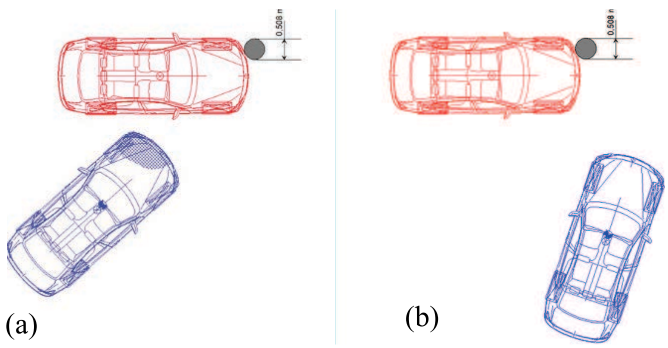


Fig. 3: BMW's initial position in simulation for t=0.000s.

The simulations considered front left wheel locking at time 0.030s for progressing deformations of the body and suspension system elements during the impact. Figures 4a and 4b demonstrate a difference in the position of the cars from the contact with the pole t=0.000s (the red car) until the stop of the cars simulated t=2.4s (the blue car).



(a) (b)

Fig. 4: 2D collision detection model (a) and 3D collision detection model (b).

Below there are provided the patterns of changes in velocity, displacement after the impact and transverse heeling angles φ, longitudinal heeling θ and angles of rotation ψ in the exes of the system related with w the BMW simulated as a function of time. Figs. 5a-c for 2D collision detection, and Figs. 5d-f – the same parameters of the BMW simulated, however for the 3D collision detection model.

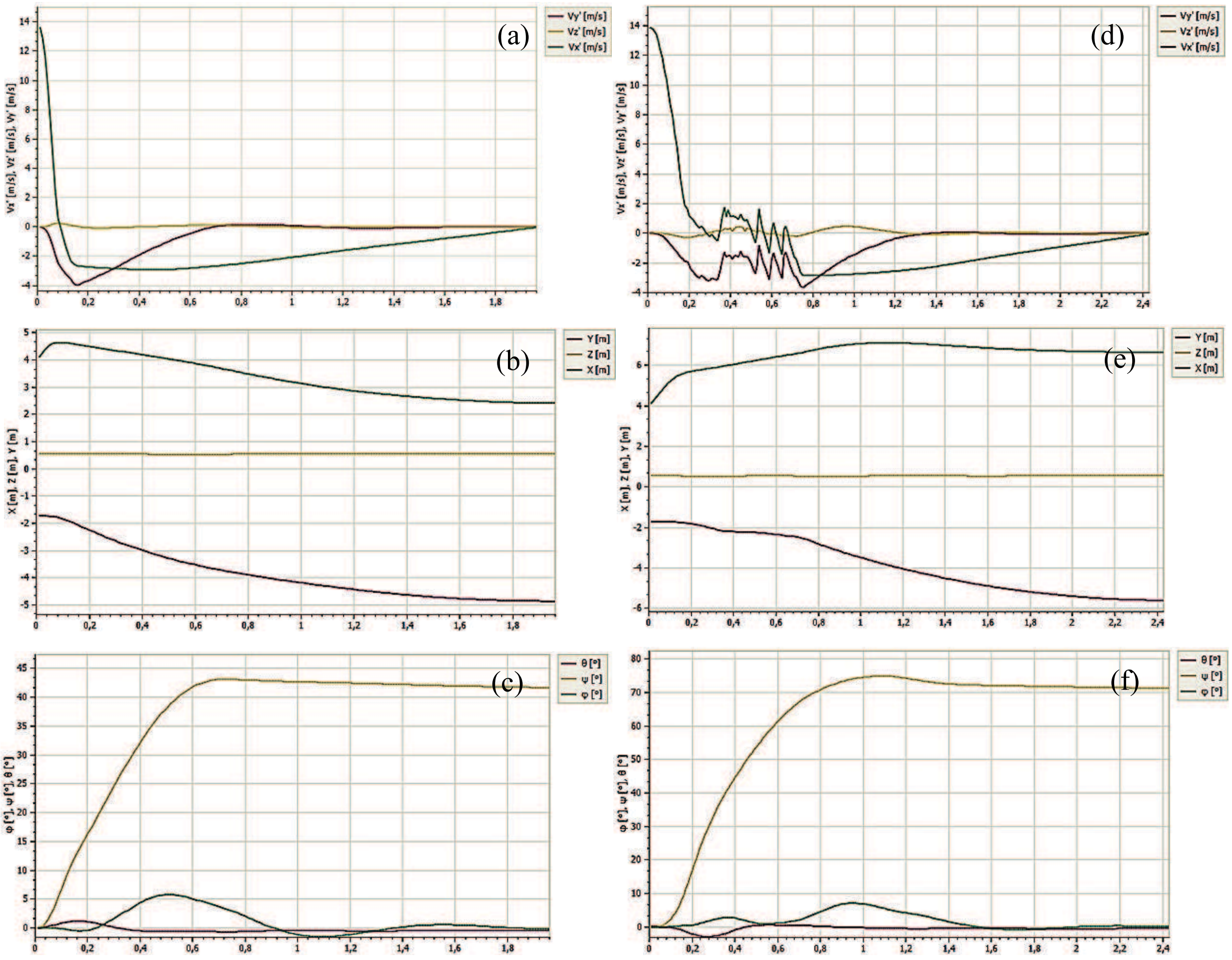


Fig. 5: 2D collision detection model (a, b, c) and 3D collision detection model (d, e, f).

5. Conclusions

The biggest differences in the course of simulations occurred for the vehicles' component velocity Vx and Vy, displacement along axis x and axis y and angles of rotation of the cars (orientation around axis z) ψ. For the crash with the same obstacle and at the same velocity and tasks depending on the collision detection model, different simulation results are generated. A different impact pattern depending on the collision detection model should also be considered for road traffic transport damage verification. One should apply different collision detection models in the program for which a similar accident pattern can be generated, just like in small overlap crash tests and should not base the results on a single simulation.

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