COMPUTATIONAL MECHANICS 35th conference with international participation
2019
Srní
November 4 - 6, 2019

Use of FEM in traffic accident analyses

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Since the 1950s, in traffic accident analysis, forensic experts have been using simple trigonometric methods of force triangles solved only with a pencil, a plastic ruler and a logarithmic ruler. Later, with the massive expansion of pocket calculators in the 1970s and 1980s, calculations accelerated, but procedures remained the same. It was only with the boom of desktop PCs that simple computer programs began to be created from the beginning of the 1990s, which were algorithmically based on the methods used so far. With the wide rise of Windows OS, faster processors and powerful graphics cards, several successful programs have gradually developed since the beginning of the new millennium. Some of these programs were probably based on algorithmic engines of racing car game simulators. These engines at that time were increasingly worked with the true vehicle dynamics based on mechanical multi-body-systems (MBS). Among such programs, which have achieved commercial use, it is necessary to mention especially PC-crash and later also Virtual-crash, with much easier and intuitive control. Gradual variants of this software from version 1.0, which solved ground plan tasks only in 2D, through version 2.0 and especially very successful version 2.2, which worked excellently since 2005 even in 3D space, further versions 3.0 and 4.0 focused mainly on improving real graphics even with rendering and also modeling realistic terrain using Google orthophotomaps, which make it easy to model a road elevation and realistic relief of the surrounding terrain.

However, MBS algorithms generally work with non-deformable models defined only by the simple outer envelope of the modeled object. However, such models usually do not contain any deformation zone elements by demanding procedures tuned in the development of real vehicles or other elements hidden under the hood (engine, transmission, cooling system components and many others). Usually, the stiffness of the individual vehicle body parts is also not known.

In the case of vehicles, only the outer contours of their shape and, in some cases, their interior contours are entered. The whole vehicle model is then composed of several hundred or several thousand usually triangular faces of various sizes so that the simplified shapes of the vehicle are sufficiently modeled.

A range of vehicle damage in these models is implemented by simplifying special procedures working only with estimating the depth of overlap of vehicles at the moment of collision (in milliseconds), estimating the impact restitution coefficient and estimating the so-called equivalent energy speed (EES). Other simplifications envisaged in MBS programs include a linear relationship between vehicle deformation and contact force. In addition, movement after impact is extremely sensitive to contact parameters, which is typical for non-linear systems. This cause differences between the results of the experiment and the simulation. Despite of these facts, the procedures described above give relatively convincing results for most traffic accidents. It should be noted, however, that the expert by the application of these procedures always obtains “some” result, which does not always mean a technically acceptable solution to the task. Although experts must have sufficient experience in entering individual task input parameters, many other important physical inputs are only predefined in the software implicitly and often do not even change them by experts. The expert can then be satisfied with the result of his simulation, which at first view makes some sense, but in fact does not fully correspond to the physical conditions. Consequently, the expert can prepare an inaccurate technical report, which can subsequently affect life fates of the road accident participants. Thus, in many other cases, the above procedures can fail.

MBS algorithms on mechanical systems of usually only a few hundred or thousand degrees of freedom, with relatively large time steps of individual iterations of solutions (0.001 to 0.01s), give fast results and thus allow a large number of different solution variants to be processed in a short time, for instance when some input parameters of the task are varied.

This paper deals with the use of nonlinear finite element (FEM) algorithms solving generally fast dynamic processes. These algorithms work with deformable models of vehicles or their components, the achieved results can in some cases bring to the task much more realistic look of the deformation process and behavior of the objects involved comparing to MBS.

Further considered procedures require much more sophisticated models requiring knowledge of a much larger range of input parameters, including a description of the mechanical properties of all structural materials. The results of such computer simulations today give a very realistic view of the deformation behavior of individual vehicles or objects during a traffic accident. Suitable complete vehicle models are now available to vehicle manufacturers, who use them in the virtual development cycle of new vehicle generations. Such models now have several tens of millions of degrees of freedom, the time step of each solution iteration is around 1 μs to be good numerical convergence.

Unfortunately, such vehicle models are generally not currently available for use in forensic practice, and the vast majority of current experts do not have enough expertise, experience and equipment to apply these methods in practice. However, even today, it is possible to solve with the use of FEM methods a number of more complex tasks where standard approaches of forensic experts fail.

The author of this paper will demonstrate several examples solved since the turn of the millennium using the software PAM-crash. The Virthuman as a scalable human body model will be introduced in some of these examples where the passengers or a vehicle crew were modelled.

Fig. 1. An example of traffic accident analysing by Virtual-crash

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