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ABSTRACT

Summary Crashworthiness analysis with the so-called explicit FE programs such as LS-DYNA [1] has reached a very mature status such that the number of real physical tests e.g. in the automotive industry has been reduced considerably. Though the element technology in the explicit programs has been mainly dictated by efficiency the quality of the results of nowadays standard crashworthiness analyses is very high and the demands for further enhancements of the programs concerning the range of applications are still increasing. The contribution is focussing on element technology, contact algorithms and particularly modeling aspects. Finally various aspects and results concerning parallel processing are presented.

Current models in crashworthiness analysis contain well beyond 500 000 elements which may be a mix of shell elements, beam elements, 3D solid elements and many connection elements such as springs, dampers with nonlinear properties. For model efficiency often larger parts are defined as rigid and for modeling almost rigid connections such as rivets often constraint conditions which are essentially small rigid bodies are used. Almost arbitrary joints and hinges can also be defined to allow a simple modeling of partially flexible connections. It is well accepted by engineers that within the models continuum theory is often violated in the vicinity of the connections, as mostly the geometrical effects appear to dominate the results.

The element technology was initially focussing on fully reduced integrated elements with hourglass control [2] though the limits concerning kinematics have been known. However, the overall efficiency of these elements allowed to analyze models with difficult, realistic geometries and with the advantage, that the Jacobian at the center of the element almost never becomes indefinite even for very large element distortions, large deformation analyses have been possible even with fairly coarse meshes. With the advent of new element technologies it was expected that the use of fully reduced integrated shell elements will vanish, however, these elements often proved to be less robust in arbitrary situations. After revisions of the original stiffness hourglass control concerning rigid body rotations the simple Belytschko-Tsay shell element [2] is still THE tool for any larger analysis. As the deformations in the so-called hourglass kinematics are controlled by computing the hourglass energy for each element any undesired kinematics is easily found in general models. For such regions then e.g. fully integrated shell elements with assumed shear strain distribution can be taken and opposite to the statements in [3] reliable results can be achieved. However, such kinematics are rarely found in the current fine meshes with element lengths of about 4 mm. For a general comparison of modeling with different shell element technologies it is referred to [4]. The situation is not that clear yet with 3D continuum elements though the stabilization suggested in [5] works robustly, in particular, in cases with larger deformations when the selective reduced integrated elements show indefinite Jacobians. However, meshing often forces the use of tetrahedral elements, which are successfully used for foam materials with large compressive deformations. A large variety of material models covering elasto-plastic, viscoplastic, viscoelastic, composite, damage, failure, nonlinear elastic with many variations can be chosen from the material library in LS-DYNA for the structural elements used in nowadays cars.

Contact is the second dominating aspect in crashworthiness analysis, as it is very important to capture the correct geometry during the structural collapse. Two parts of the contact algorithms have to be distinguished – the search part and the contact treatment part. Fully automatic searches with fairly little computational cost are nowadays available, such that unclear situations at corners and edges are almost never encountered in fine models with the very small time steps used in explicit time integration. Detailed local searches and the storage of some localization properties for each contact segment also lead to accurate and fairly efficient algorithms concerning computational overhead and memory requirements. The addition of alternative algorithms such as the pinball algorithm [6] further improve the efficiency of the search and the robustness in some situations in particular in combinations with the standard search algorithms. Contact treatment is mostly performed with the penalty method. As only linear shape functions are taken for the description of the contact resp. surface segments simply checking the penetration of nodes into the opposite surfaces and applying a force perpendicular to the penetration is needed. The weakness of this approach concerning too large single forces is known. However, due to nowadays more accurate search algorithms and the small time steps this is mostly avoided and the sophisticated penalty adjustments for materials with very different bulk moduli often encountered in contact restrict any overly large response. Even very complex situations as airbag unfolding with multiple closely spaced layers are handled without artificial penetrations.

Over the last five years considerable effort in the development of LS-DYNA was spent for parallelization with domain decomposition. The original algorithms could be well adjusted resp. new algorithms in particular in contact were added and a very good speed-up has been achieved on all available computers even up to rather high processor numbers. The latter achievements also allow multiple repetitive analysis of rather large models with e.g. so-called stochastic modifications and for optimization with response surfaces. The latter methods open the way for considerable improvements of the design of the structures concerning robustness as well as e.g. weight reductions.

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