Explicit FEM in analysis of crash elements

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Abstract

The authors have presented some chosen examples of application of Explicit Finite Element Method in a field of crash simulations in rail cars. First two examples focus on use of different materials and physical phenomena to absorb energy in case of dynamic impact. These are machining of steel cylinder and crushing of composite cylinder. Bumper with machining of cylinder is since few years in normal exploitation and composite bumper needs several developments and tests. Third example describes typical crash analysis of rail car with all interesting issues which include special modelling techniques, dummy and energy absorbing zone with special bumpers. Also requirements for such an analysis will be explained. For composite materials there will be shown results of several material and impact tests.

Keywords: explicit, fem, crash, rail, bumper, energy, ls-dyna

1. Introduction

Explicit Finite Element Method is nowadays basic tool in each type of industry, especially in automotive, aircraft and rail. It saves cost of product development and simplify verification process of different solutions and materials. There are additional tools developed to simplify modelling of crash structure including dummy positioning, seating acceleration sensors etc. In rail industry, these costs can be especially great due to size of cars and standard requirements. Nowadays impact behaviour of structures can be simulated in design stage with great accuracy. Standard EN 15227:2008 (Railway applications - Crashworthiness requirements for railway vehicle bodies) is main document describing all issues referring to crash requirements in rail industry.

Explicit Finite Element Method has been found as excellent tool to solve complex tasks that include large deformations of structures, great inertia effects. Also analysis of contact is developed in several algorithms which make it much easier to perform and control than in implicit solvers.

2. Requirements concerning crash analysis of rail cars

Standard EN 15227:2008 (Railway applications - Crashworthiness requirements for railway vehicle bodies) describes all details concerning crash analysis of rail cars. Nowadays each design at least in Europe must fulfil its requirements. There are four categories of vehicles including trams, locomotives, coaches and metro. For these categories exist several scenario for crash accident: front end impact between two identical train units, a front end impact with a different type of railway vehicle, impact with a large road vehicle on a level crossing and impact onto low obstacle. Depending on car category there are different collision speeds and also not all categories require all scenario to be performed.

For some of cars, energy to be absorbed can even reach 20 MJ due to speed and need of including several cars behind analysed one.

Designing of crash zones is now on of main issues in car construction because it will determine structure in at least front part. High speed trains are equipped with special joints that absorb large amount of energy but at first have crash zone based e.g. on cylindrical or rectangular tubes.

Concerning requirements to be satisfied, most important refers to overriding of vehicles, maximum mean deceleration and survival space for passengers and driver. Survival space for passengers cannot be e.g. shortened more than 50 mm for 5 m of construction.

3. Explicit Finite Element Method

Explicit Finite Element Method is based on Central Difference Method. Ls-Dyna was originally developed for military purposes to model blows of bombs but rapidly was used in several fields.

Explicit finite element method is widely used in analysis of phenomena of energy absorbing. Due to its large capabilities in a field of highly nonlinear and very short term actions it is main tool in designing either whole cars or particular elements. Another advantage is very detailed material library with damage models of almost all materials used in construction which include e.g. metals, composites and foams.

4. Machining

First part is focused on using metal machining as a main mechanism that absorb energy.

Design using machining has an advantage of absorbing large amount of energy comparing to the size of a bumper and also allows easy controlling of this energy by optimization of an item shape. Main disadvantage are cost of production and asymmetric load acting on bumper which determine higher number of tools.

Machining due to its complexity which includes large plastic deformations, temperature dependency of parameters is very difficult to simulate with numerical methods but there are several solutions for that e.g. material models and meshless methods.

FEM was used to optimize shape of a tool, material parameters and verify tool wear and thermal conditions of analysis. Results are compared to crash tests on a test bench recorded using fast camera system. Different techniques were used for this analysis and include also meshless methods. Very important issue in analysis was modelling of tool wear which was performed with implicit solvers due to presence of special algorithms applied in MSC.Marc. Wear of tool for typical analysis was usually at least 2-3 mm.

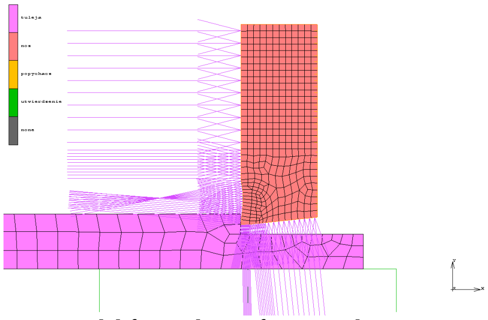

Figure 1: Model for analysis of wear tool

5. Crushing of composite

Second example concerns use of composite materials as mechanism of an energy absorbing. These materials are widely used either as structural elements or main component of crash structure due to large capabilities in this phenomena. Composites also have great ratio of energy absorption to weight and are much more effective than any steel or aluminium parts, specially carbon composites. Also production techniques are improved all the time which is one of crucial aspects for decreasing of costs which are much larger than for metal materials.

There are several damage models applied in Explicit FEM that can be used to analyse delamination, matrix cracks, debonding which are one of main mechanisms of energy absorbing in these materials. These models exist either for shell or solid models. There are still a lot of challenges in analysis of composites with FEM due to complicated material model based on anisotropy and complex behaviour during damage of a model.

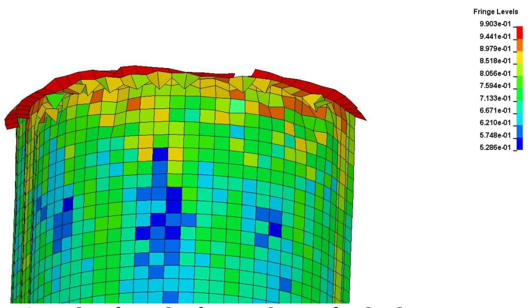

Figure 2: Sample of results for crushing of cylinder

Figure 3: Example of crushed specimen

6. Crash simulation

Crash simulation of rail car is usually based on model from structural analysis and require more detailed modelling of parts which should absorb energy or can come into contact. LS-Dyna has special contact algorithms for such a cases. Great care must be paid to minimization of initial penetrations which can change balance of energies. Material modelling require additional material curves for plasticity but also strain rate must be carefully considered. Another special approach must be paid to verification of allowable decelerations and safety areas. These can include modelling of driver chair with dummy.

Due to large time of analysis, there are additional tools that support analysis e.g. rigid walls which can replace one of the cars in some scenarios, algorithms that limit hourglassing due to use of elements with reduced integration.

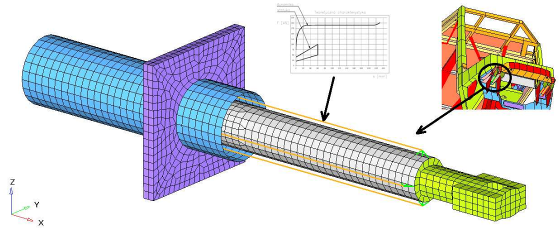

Figure 4: Crash bumper based on machining

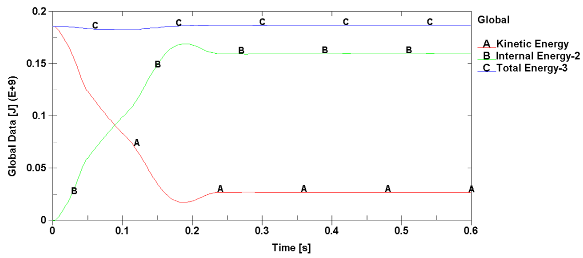

Figure 1: Energy verification for crash analysis

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