Finite Element Modeling of the Crash-Tests for Energy Absorbing Lighting Columns

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Abstract

Finite Element system LS-DYNA is used in this project to perform contact-impact nonlinear dynamic analysis of the lighting column crash-test with vehicle. FE spatial discretization is achieved by the use of shell and solid elements. Developed 3D CAD and FEM models of different types of columns that allowed simulation of the following nonlinearities: impact at different vehicle speed, plasticity in column and vehicle parts, contact interaction between simulated objects, progressive damage in column laminates. The resultant simulated deceleration curves allowed calculation of head injury criteria (HIC) and safety estimation for all columns crash tests.

Keywords

Crash-test, composite, energy absorption, FEA

1 Introduction

National Governments at EU are committed to reduce the number and severity of accidents on the road caused by impact to roadside objects. The European Parliament proposed in 1998 that primary action should be taken to halve fatalities by the year 2010. Owing to that, standard EN 12767 was established, in which safety categories are defined for support structures, direct rules for crash testing and also for interpretation of crash test results.

A procedure to reduce the number and severity of accidents is to use passive safety infrastructure: especially lighting columns with adequate energy absorbing properties are feasible to hazardous sites. In general, there are two different approaches to minimize the effect of collision when lighting columns are considered:

- **Energy absorbing structures** to slow the vehicle considerably, and thus the risk of secondary accidents with other structures, such as trees, pedestrians and other road users may be reduced, and
- **Non-energy absorbing structures** that allow the vehicle to continue moving after the impact with a controlled reduction in speed.

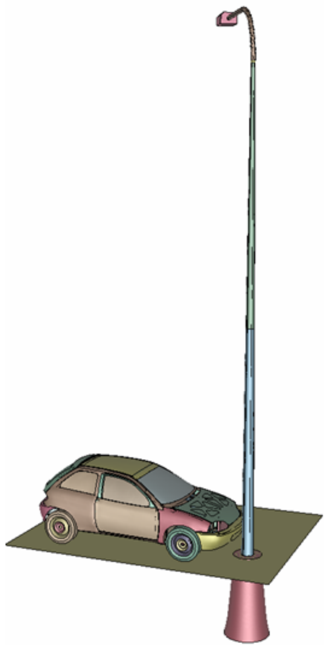

Figure 1. CAD Model of lighting column and vehicle

Generally, the structure of the non-energy absorbing column, which may be detachable, is made of wood or rigid steel. During an impact, the column gets loose from a slip base or by other similar controlled mechanism.

Energy absorbing columns have impact properties to decelerate a vehicle and absorb energy during an impact. The desired behaviour can be achieved with a rigid lightweight structure that also have elements with suitable energy absorbing properties. During the impact, the energy absorbing structure flattens and rolls under a vehicle, thus absorbing energy. Existing column products usually have rigid shell manufactured of steel, aluminium or composite that ruptures during a crash. Energy absorbing elements can be made of steel, composites, wood etc.

2 The structure and production process

The Fibrocom Oy's patented channel composite laminate is formed of 3D –glassfibre weave, which has parallel tubular channels along the walls of the conical column structure. The channels can be empty or filled with other materials. In this case, some columns have longitudinal stiffeners, which significantly improve the energy absorption properties. The resulting structure is a stiff and lightweight structure manufactured in a process vacuum infusion. Vacuum atmosphere improves driving of a resin into a laminate, gives a better fibre-to-resin ratio and also reduces the total process time.

Figure 2. Deformed column and vehicle after impact of 100 km/h. Impact tests performed by Helsinki University of Technology, Laboratory of Highway Engineering

3 Simulations for further development

St.Petersburg State Polytechnical University, Computational Mechanics Laboratory (CompMechLab) performed crush tests simulations for several types of composite columns at different car speed values. Finite element (FE) system LS-DYNA is used in this project to perform contact-impact non-linear dynamic analysis of the construction. LS-DYNA contains a lot of methods and algorithms to give solutions for various types of complicated mechanical problems. Contact-impact algorithms make it possible to simulate dynamic contact interaction of structure parts.

Three-dimensional FE model (Figure 3) is achieved by the use of shell and solid elements. Developed 3-D CAD and FE models of different types of columns allowed simulating the following nonlinearities: impact at different vehicle speed, plasticity in column steel reinforcing parts and vehicle parts, contact interaction between simulated objects with large displacements/rotations/strains, progressive damage in column laminates.

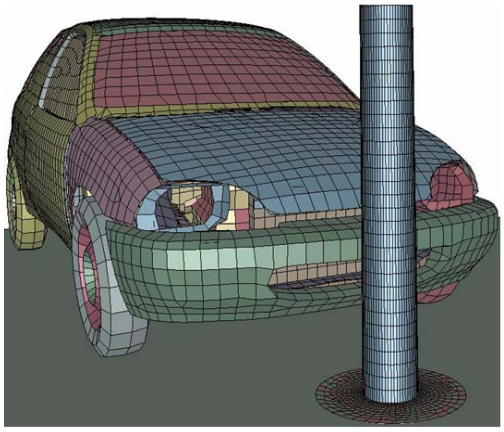

Figure 3. Three-dimensional finite element model

3-D FE model of real car prototype based on FHWA/NHTSA National Crash Analysis Center prototype includes radiator, engine, front and rear suspensions, brake system and many other parts with ability of contact interaction and nonlinearities in material behavior. Prototype design was debugged to make approximate similarity with car in experiment: radiator and engine were positioned as at Peugeot 205, total mass of Geo Metro is equal to 1030 kg Peugeot mass. Column 3-D FE model includes column stand, reinforced composite laminates, bracket with lanterns (single or double). Totally 216 different materials considered in car prototype with lighting column model. During the research authors considered several columns that differ with various quantities of reinforcements, column total height and outer and inner diameters. All that allowed simulating, analyzing and controlling of composite columns energy absorbing properties.

4 The FE simulation of column crash-tests

The process of vehicle deceleration with column can be divided into two phases (Figure 4) – first is impact and second – sliding of column pipe under vehicle. First phase characterize the maximum peak of deceleration and defines the column safety class. The head injury criteria (HIC) value mostly depends on the peak parameters.

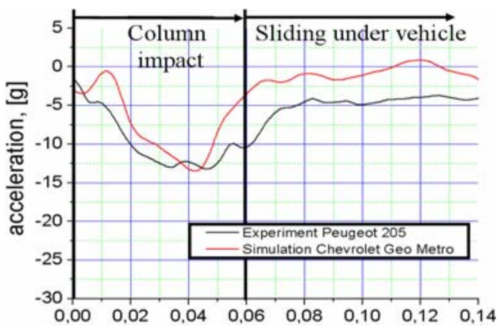

Figure 4. Deceleration curve obtained at FEM at 100km/h impact speed in comparison with experiment

The duration of this phase for all columns is not more than 0, 06 second.

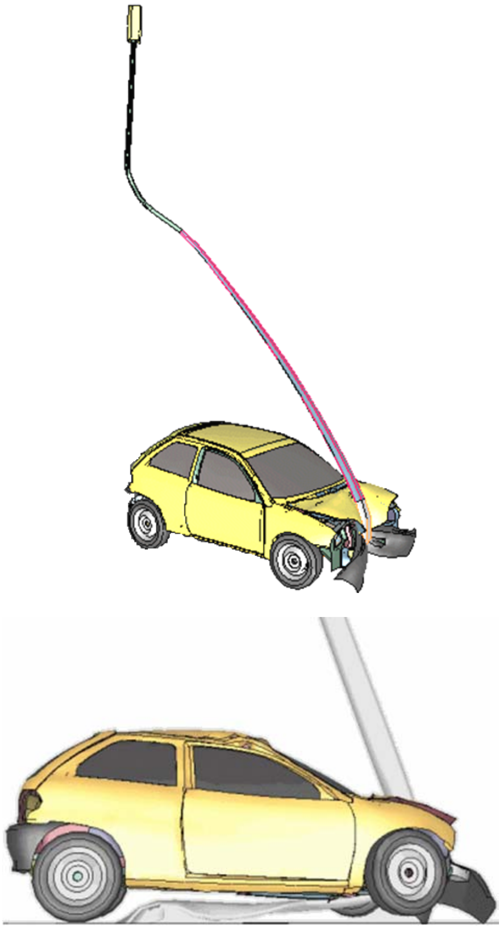

Figure 5. Column impact and sliding under vehicle

Main parameters influencing maximal deceleration value are column cross section, outer diameter, number of reinforcing bars and bar diameter. The second phase (Figure 5) is passing with low values of deceleration up to vehicle stop. That's why it is enough to analyze the first phase for safety estimation. Because of the maximal peak of deceleration observes at duration of the first phase. The first phase analysis showed that the main energy dissipating factors are progressive damage at column laminate and plasticity at reinforcing bars (Figure 6). Finite element modeling of composite damage is based on applying of "Chang-Chang" criteria [Chang and Chang 1987]. The finite element death happens when $\boldsymbol{F}_{matrix}>1$, $\boldsymbol{F}_{comp}>1$ or $\boldsymbol{F}_{fiber}>1$, then the material constants set to zero. The matrix cracking failure criteria determines from:

$$F_{matrix} = \left(\frac{\sigma_2}{S_2}\right)^2 + \bar{\tau} > 1 \Rightarrow \nu_1 = 0, \nu_2 = 0,$$ the

compression failure criteria:

$$F_{comp} = \left(\frac{\sigma_2}{2S_{12}}\right)^2 + \left[\left(\frac{C_2}{2S_{12}}\right)^2 - 1\right]\left(\frac{\sigma_2}{C_2}\right) + \bar{\tau} > 1 \Rightarrow$$

$$E_2 = 0, \nu_1 = 0, \nu_2 = 0$$

Final failure mode due to fiber breakage:

$$F_{fiber} = \left(\frac{\sigma_1}{S_1}\right)^2 + \bar{\tau} > 1 \Rightarrow$$

$$E_1 = 0, E_2 = 0, G_{12} = 0, \nu_1 = 0, \nu_2 = 0$$

Where is $\bar{\tau} = \dfrac{\dfrac{\tau_{12}^2}{2G_{12}} + \dfrac{3}{4}\alpha\tau_{12}^4}{\dfrac{S_{12}^2}{2G_{12}} + \dfrac{3}{4}\alpha S_{12}^4}$ - the ratio of the shear stress to the shear strength.

Here considered: $\boldsymbol{S_1}$ – longitudal tensile strength, $\boldsymbol{S_2}$ – transverse tensile strength, $\boldsymbol{S_{12}}$ – shear strength. $\boldsymbol{C_2}$ – transverse compressive strength, $\boldsymbol{\alpha}$ – nonlinear shear stress parameter defined by material shear stress-strain measurements.

The developed finite element models of laminated reinforced columns allowed FE modeling of these processes and obtaining a good correspondence with full scale natural experiments.

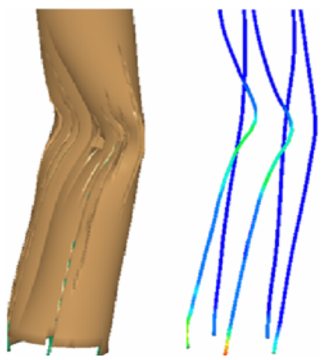

Figure 6. Progressive damage at column laminate and equivalent plastic strain in reinforcing bars

Values of maximal deceleration show a good correlation with experiment results. The obtained FE results, with developed models, showed that correctness of FEM-computations approves with that experiment maximal deviation for maximal deceleration stand in 14% value (Figure 7), and good correlation between experiment and simulated deceleration curves.

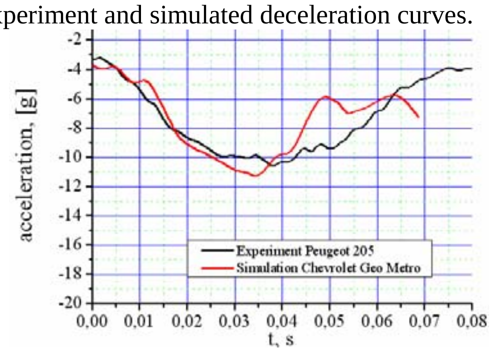

Figure 7. Deceleration curve obtained at FEM at 100km/h impact speed in comparison with experiment

5 Crash safety estimation

The Head Injury Criteria (HIC) is currently used to assess head injury potential in automobile crash test dummies. It is based on the resultant translational acceleration rather than the frontal axis acceleration. The resultant simulated deceleration curves allowed calculating HIC – the unique among Federal Motor Vehicle Safety Standard (FMVSS) – and estimate safety reliability for all columns crash tests. All HIC values are below injury risk (Figure 8) that shows a safe impact in all column types, and it is important to emphasize that all values are acceptable with safety standards for very young children and adults.

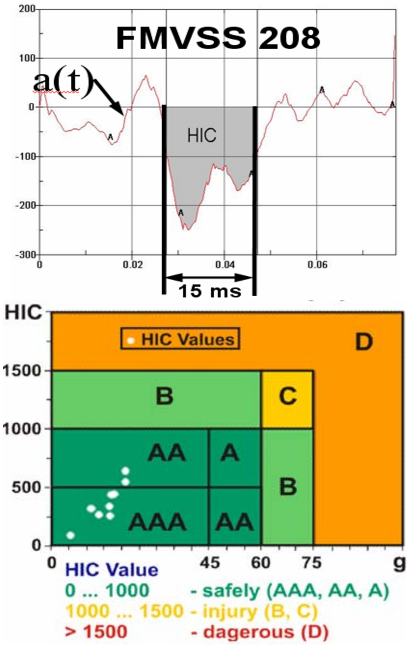

Figure 8. HIC estimation and ranks of evaluation for injury risk

Computed HIC values combined with maximal deceleration values provided validity of safety estimation. The 36 millisecond interval for HIC calculation is meant to encompass the maximum loading for impact waveforms which last longer than 36 milliseconds. Relatively short duration waveforms tend to be associated with head contact whereas longer duration HIC intervals tend to be associated with head deceleration without impact. As of 2000, the NHTSA final rule adopts limits which reduce the maximum time for calculating the HIC to 15 milliseconds (HIC_{15}) vs. the prior HIC_{36}.

The full scale three-dimensional finite-element simulation on the base of developed models allowed analyzing of the whole process of crash. Also the important things for crash safety are the outgoing speed and the deformed vehicle after crash (Figure 9). The total deformations of the front vehicle part and the depth of deformations at cockpit appear to be acceptable for safe according to FMVSS 201, 208.

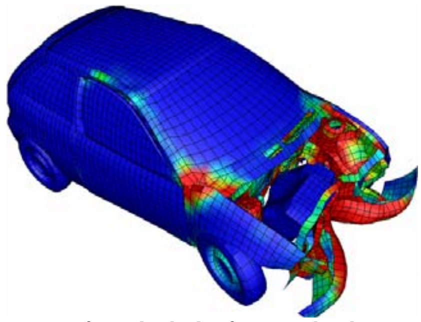
Figure 9. Deformed vehicle after stop, the plastic strain intensity.

Tehomet Oy’s channel composite lighting column won an award in the Energy and Industry category at the JEC Composite show 2006 in Paris. Lighting pole with controlled energy absorption characteristics aim is to make impacts with vehicles less dangerous. The pole can blend in with the urban landscape. Europe’s specific impact standards – the pole achieved the best EN 12767 classification.

Conclusions

The illustrated FE approach for complex crash problems solution allowed simulating the whole crash process and providing recommendations to manufacturer, to estimate safety and injury risk that shows a safe impact in all column types. Computed HIC values combined with maximal deceleration values provided validity of safety estimation.

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