Finite Element Modeling and Analysis of Crash Safe Composite Lighting Columns, Contact-Impact Problem

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Abstract

Three Finnish associates, Tehomet Ltd, Fibrocom Ltd and Mikkeli Polytechnic Research Center YTI developed an internationally awarded energy absorbing lighting column product family in 2005. The design and dimensioning were assisted with static FEM computations, preliminary impact tests and full-scale impact tests made by YTI.

The CompMechLab helped these associates in product optimization and further development by developing lighting column FE-models with sufficient energy absorbing properties, by fitting the model to obtain similar deceleration curves with real car crash tests, and to provide recommendations concerning the design of new, higher columns.

Developed fully 3-D CAD and FE models of different column types featured the simulation of the following nonlinearities: dynamic impact at different vehicle speeds, plasticity in column and vehicle parts, contact interaction between the simulated objects and progressive damage in column laminates.
3-D FE model of the impact car was based on FHWA/NHTSA National Crash Analysis Center prototype including 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 modified to get approximate similarity with the Peugeot 205 car used in the experiments. Column 3-D FE model includes column stand, reinforced composite laminates and bracket with lanterns (single or double). Al together 216 different materials were used in the FE-model of the car and the lighting column.

The resulting simulated deceleration curves allowed calculating Head Injury Criteria – conforming Federal Motor Vehicle Safety Standard – and estimating safety reliability for all columns crush tests. Computed Head Injury Criteria values combined with maximal deceleration values proposed the constructions to be safe ones.

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 [1−7] 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:

a) **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

b) **Non-energy absorbing structures** that allow the vehicle to continue after the impact with a controlled reduction in speed.

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.

Impact tests by Helsinki University of Technology

Crash tests according to EN 12767 were performed by Helsinki University of Technology, Laboratory of Highway Engineering at the airport of Pori, Finland. The impact vehicle in each test was Peugeot 205 with identical mass to the bogie vehicle, 950kg. Decelerations for the computations of ASI–values were acquired with acceleration sensors, THIV –value was defined from high speed camera files.
The occupant safety level is defined with ASI- and THIV –values. ASI (Accelerated Severity Index) is a computational value of accelerations, which the occupant undergoes during the impact process. THIV (Theoretical Head Impact Velocity) gives information concerning the deceleration of the occupant's head caused by the deceleration of the vehicle.
Several tests with slightly varying structures for 10m high columns were performed during the summer 2005. All the ASI–results of 100 km/h test speed are shown in Fig. 1. The results of selected test are summarized in Table 1.

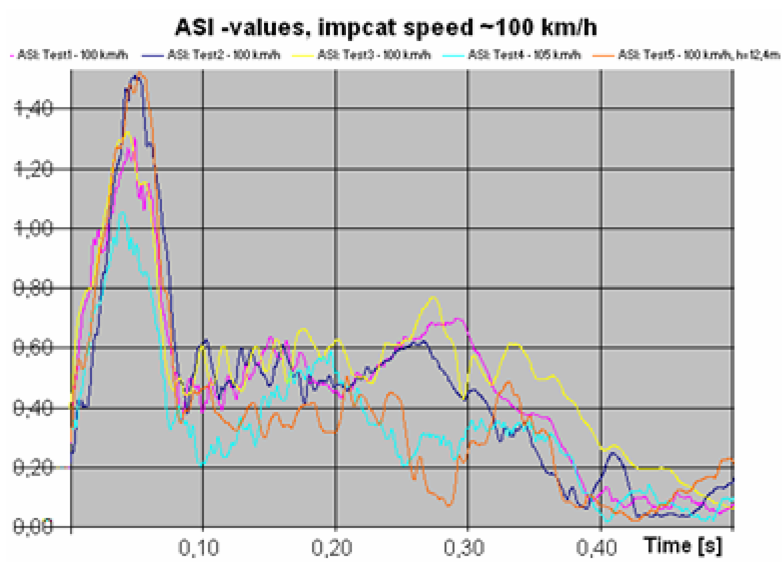


Fig. 1. ASI values

Table 1.

Height	Bracket projection	Lantern's weight	Column plinth	Target speed	Measured speed	ASI	THIV	Safety category
10,0 m	2,5 m	8 kg	RBJ-5SP	100 km/h	105 km/h	1,0	26 km/h	HE 3
10,0 m	2,5 m	8 kg	RBJ-5SP	35 km/h	33 km/h	0,5	22 km/h	HE 3
12,4 m	2,0 m	8 kg	RBJ-6SP	100 km/h	102 km/h	1,5	32 km/h	HE 1

Lighting column with height of 10 m obtained the best HE–energy absorption category with the highest occupant safety class 3. The column with height of 12,4 m reached only HE 1 –class due to overgrown vertical deceleration values. Fig. 2 shows the deformed column (height 12,4 m) after crash test. Research and development to further improve the performance of the higher column is in progress.

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

Lighting Columns Crash Tests Finite Element Simulation

St.Petersburg State Polytechnical University, Computational Mechanics Laboratory (*CompMechLab*) performed crush tests simulations for several types of composite columns at different car speed. Finite Element (FE) system LS-DYNA [8] 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 (3-D) FE model (Fig. 3) is achieved by the use of shell and solid elements. Developed fully 3-D CAD and FEM models of different types of columns (Fig. 4) allowed simulating next nonlinearities: impact at different vehicle impact 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.

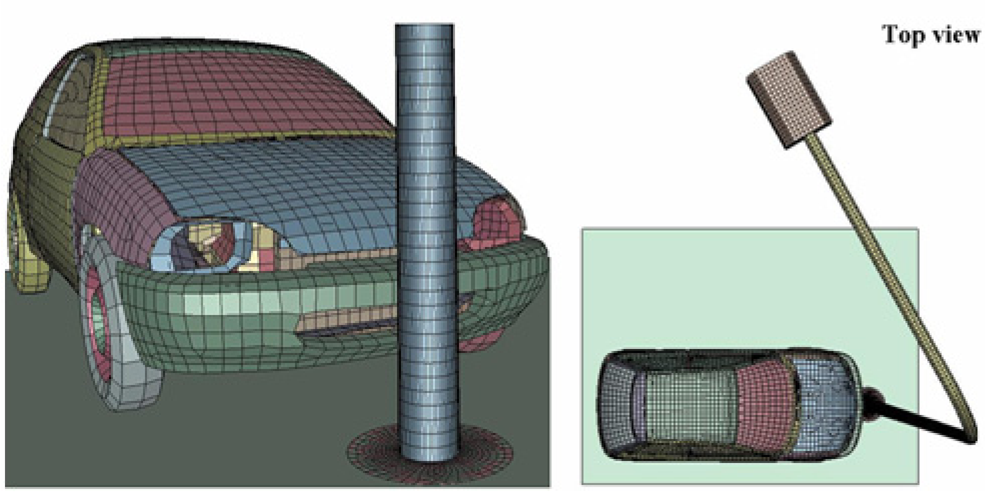


Fig. 3. Three-dimensional finite element model

3-D FE model of real car prototype based on FHWA/NHTSA National Crash Analysis Center (www.ncac.gwu.edu) 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 debugged to make approximate similarity with car in experiment. Especially, radiator and engine positioned as at Peugeot 205, total mass of Geo Metro is equal to 1030 kg Peugeot mass.

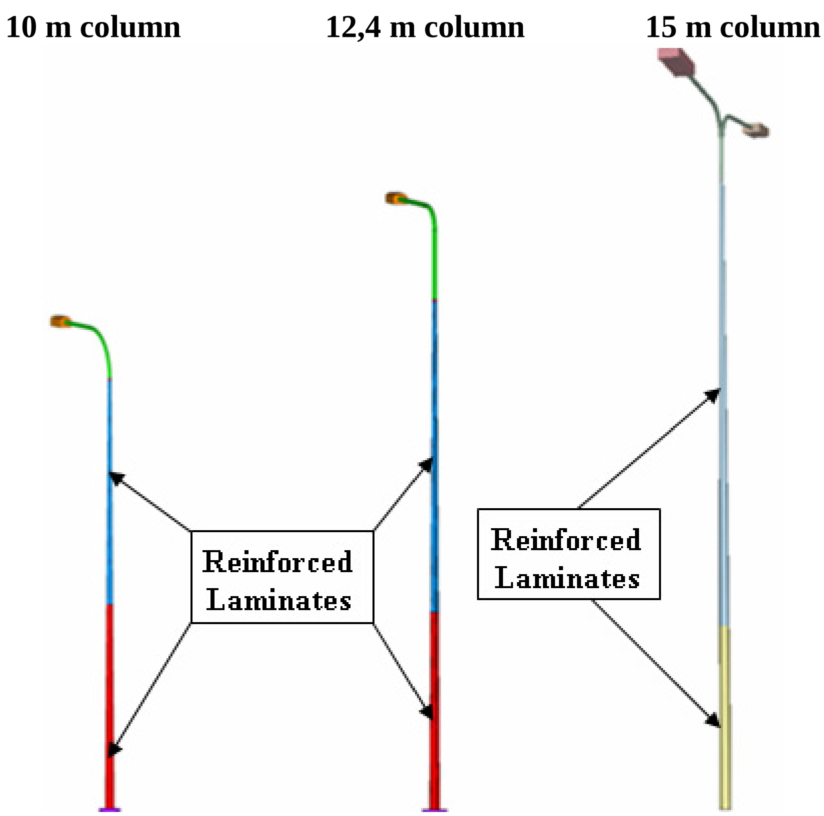
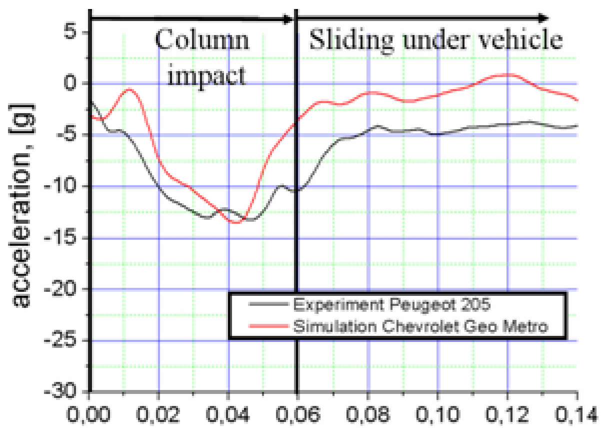


Fig. 4. Lighting columns 3-D models

Column 3-D FE model includes column stand, three different reinforced composite laminates, bracket with lanterns (single or double). Altogether 216 different materials considered in car prototype with lighting column model. Experiment with computed deceleration curves comparison and deformed column view at the peak of deceleration are showed on Fig. 5.



Experiment **FE LS-DYNA Simulation**

time = 0.04 s.

Fig. 5. Experiment with computed deceleration curves comparison

The process of vehicle deceleration from 100 to 0 km/h by column can be divided into two phases (Fig. 5) – first is impact and second – sliding of column pipe under vehicle. First phase characterize the maximum of deceleration peak. The duration of this phase for all columns is not above 0,06…0,1 sec. Main parameters influencing on maximal deceleration value is column cross section, outer diameter, number of reinforcing bars and bar diameter. The second phase is passing with low values of deceleration up to vehicle stop. That's why it is enough to analyze the first phase. Because of the maximal maximum peak of deceleration observes at duration of the first phase of impact.

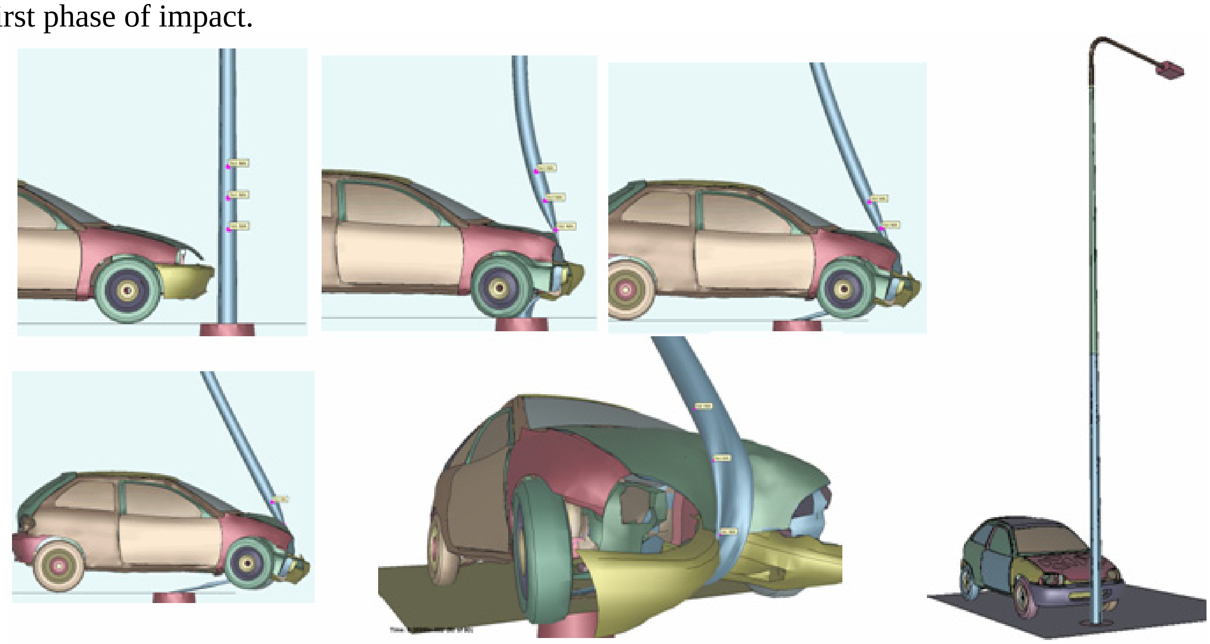


Fig. 6. Freeze frames of column sliding under vehicle

Fig. 7 illustrates freeze frames of impact at t=0.04 sec (this time point is a maximum for deceleration curve) for large 15 meter high lighting column (10 reinforcing bars in laminate structure) and deceleration curve at 100 km/h speed in comparison with 10 meter column and 15 meter column with decreased number of reinforcing steel bars in pipe laminate structure.

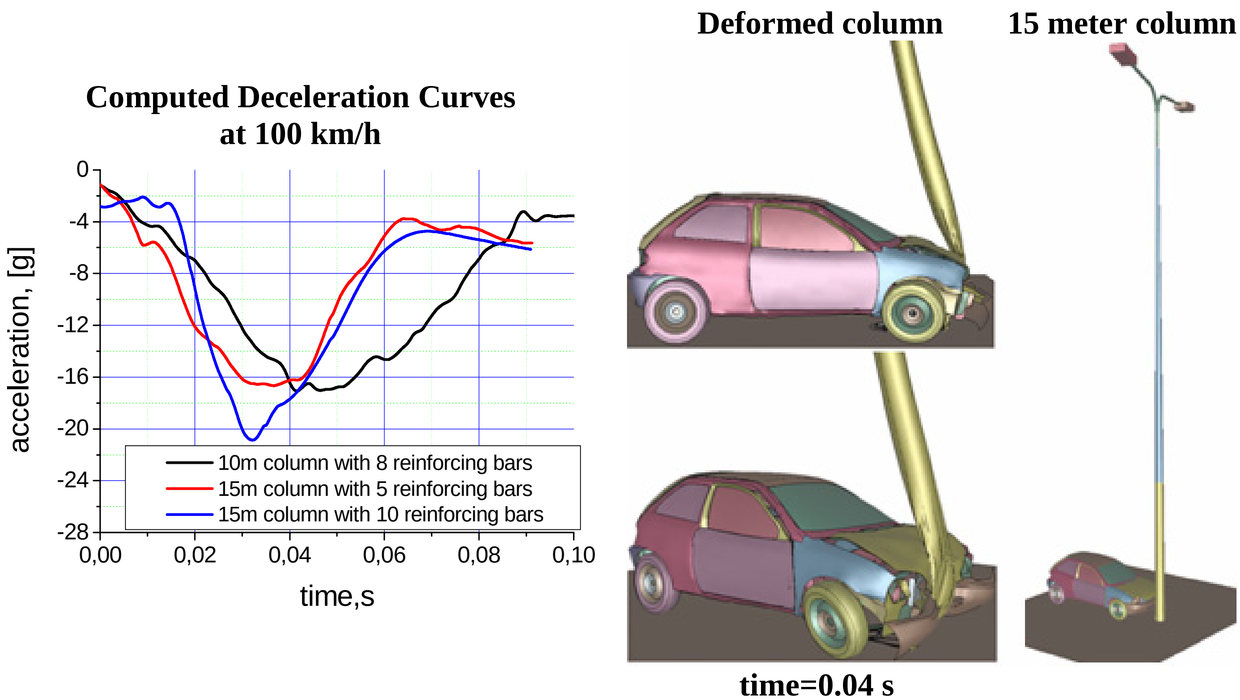


Fig. 7. Deceleration curve at 100 km/h speed in comparison with 10 m column and 15 m column

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

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 crush tests. Fig.8 illustrates comparison between real experiment by Helsinki University of Technology and LS-DYNA FE simulation results of first 0.15 sec of impact. Deformed vehicle and column after stop shown on Fig. 9. Some difference explains with differing hoods of Peugeot 205 and Chevrolet Geo Metro.

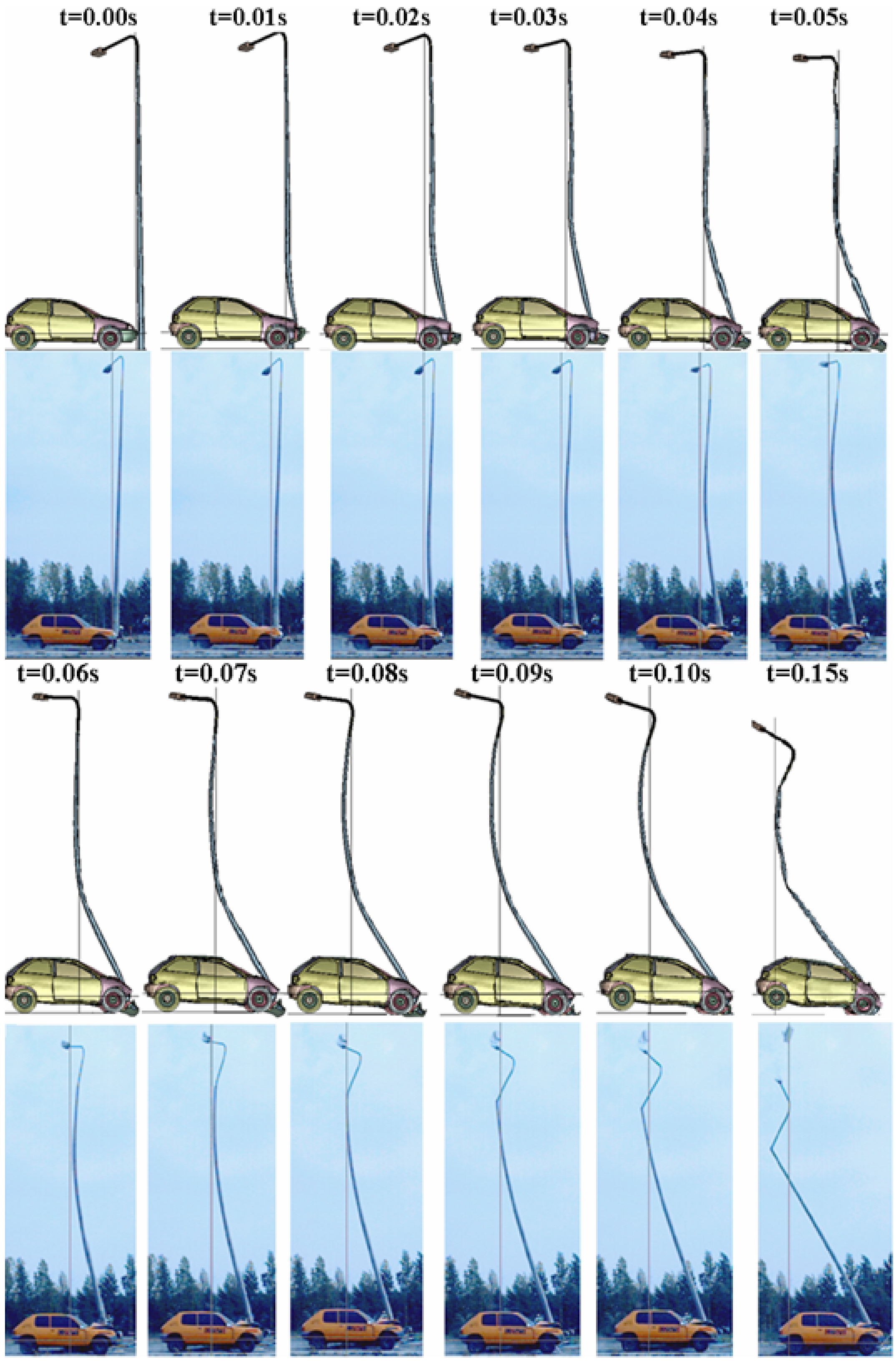


Fig. 8. Freeze frames of 12 m column impact

Bending of column at impact comparison between experiment and simulation shown on fig.8 start differ at time 0.07 sec, because of fracture at joint of column pipe and lantern bracket. But analysis of column without bracket showed that lantern bracket influence insignificantly (table 2) on maximal value of deceleration. Column with bracket maximal deceleration stay at 16,42g and without bracket remain at 16,36g.

Experiment **FE LS-DYNA-Simulation**

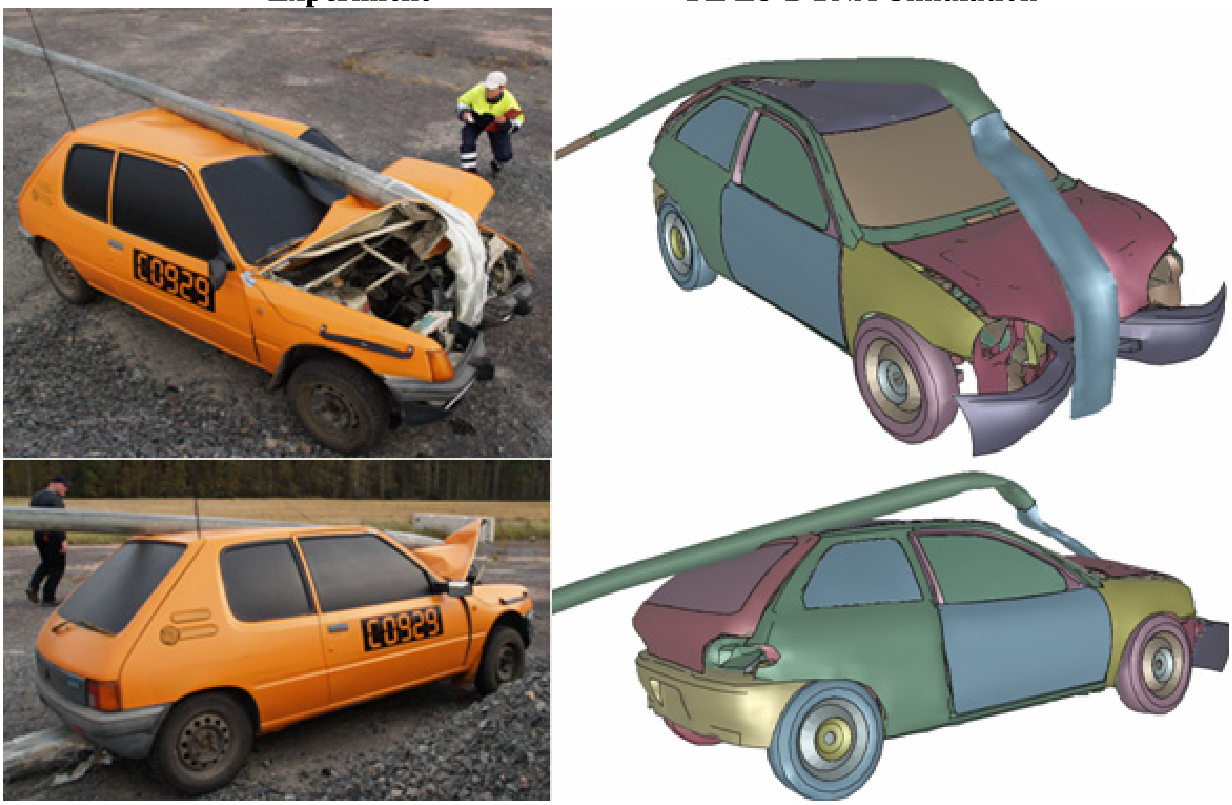
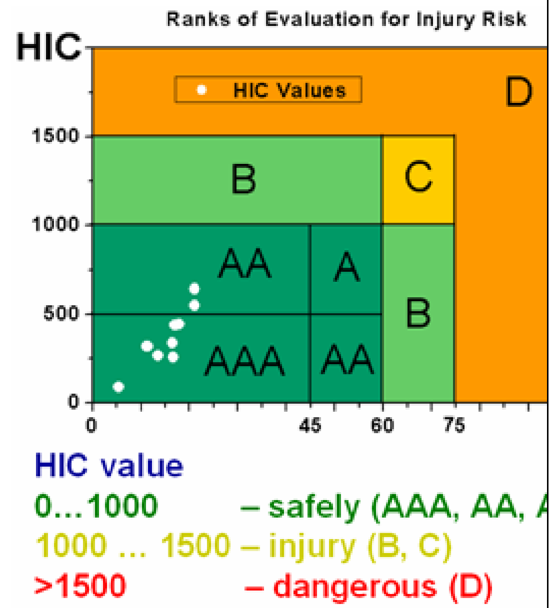


Fig. 9. Vehicle after stop

All HIC values are below injury risk (Table 2) that shows a safe impact in all column types (different height, pipe outer diameter – Dn and various number of reinforcing bars), and it is important to emphasize that all values are acceptable with safety standards for very young children and adults. 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 ms. 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 [9] final rule adopts limits which reduce the maximum time for calculating the HIC to 15 milliseconds (HIC_{15}) vs. the prior HIC_{36}.

Table 2. Computed HIC and maximal deceleration values

Column Type	HIC_{15}	Deceleration, g
10 meter 5 reinforcing bars 35 km/h	89,15	5,42
10 meter 5 reinforcing bars 105 km/h	320,70	11,32
10 meter 6 reinforcing bars 100 km/h	338,40	16,42
10 meter 8 reinforcing bars 100 km/h	444,00	17,12
12,4 meter 5 reinforcing bars 100 km/h	440,20	13,10
10 meter 6 reinforcing bars Dn=220mm (Dn=185mm) 100 km/h	266,90 (338,40)	13,45 (16,42)
10 meter 6 reinforcing bars column without bracket 100 km/h	256,72	16,36
15 meter 5 reinforcing bars 100 km/h	549,00	17,20
15 meter 10 reinforcing bars 100 km/h	643,00	21,30



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