# On the influence of shell element properties on the response of car model in crash test

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## 1 Introduction

It goes without saying that numerical simulations play important role in the modern engineering practice. Contemporary CAD environments combined with FEM solvers, along with computer power of modern processors, give the engineer fast and efficient tool. Ultimately, however it is the user alone who is responsible for the correctness of the results. As long as the FEM calculations remain in the sphere of academic exercise, the inevitable errors/mistakes resulting from improper use of FEM systems may postpone scientific development of some ideas. This is not the case however when industry application of FEM is considered as it usually involves substantial financial or other responsibility. In particular, we may mention these applications when human safety is a key factor.
In this area Ls-Dyna has its special position as a tool for simulation of car collisions. Apart from car manufacturers the code is used also by the producers of safety barriers who must adhere to the specifications of specific standards. In Europe, as of March 2017, the current state of affairs is given by EN1317-2010 standard. These include, among others, precise definitions of initial conditions for car and the placement of the car relative to the analyzed restraint system. While such precision is necessary to allow comparing different barriers it is not sufficient to cover the abundance of the real-life situations.
As a part of the research project jointly funded by National Centre for Research and Development (NCBiR) and General Director for National Roads and Motorways, Poland the present authors are responsible for numerical simulations of various real-life scenarios that do not conform to those of EN1317-2010 standard.
To model the barrier-car collision we use car models that are freely available, correcting them when necessary however. The major effort is put on the correct recreation of barrier geometry along with proper boundary conditions and connections between barrier parts. As far as spatial discretization is concerned the majority of car's and barrier's parts are modeled with shell elements. In this report we study the influence of some Ls-Dyna control cards that affect the behavior of shell elements used in FEM simulations of crash tests.

## 2 Shell element modeling

Finite shell elements are widely available in commercial FEM platforms. However, there is no general consensus which of the multitude of approaches is the best one. Thin or thick finite elements, solid-shell elements, 5/6 dof finite elements etc are the names assigned to various formulations among different FEM systems. However, it seems that the most popular approach is that known as the Reissner-Mindlin shell theory, although the name is not entirely correct, e.g. [1]. Among composite material analysts it is more common to use first-order-shear-deformation (FOSD) name. Putting aside the name, in both approaches the transverse shear distribution across the shell thickness is constant. Thus, the shear correction factor, e.g. [2][3][4][5], was introduced to the FOSD shell elements theory to alleviate this weakness.
Denoted by SHRF in Ls-Dyna, by default has its value assigned to 1.0 although 5/6 is recommended in the manual e.g. [6]. However, we found that some of the k-files of car models come with SHRF set to zero which is not entirely correct from the theoretical viewpoint, although Belytschko and co-workers argue that letting shear factor to zero has little effect for thin shells. We should bear in mind that works of Reissner or Mindlin, see for instance [7] estimate the shear correction factor value as 5/6 [8].
Being the explicit code, Ls-Dyna offers primarily reduced integration elements with appropriate hourglass control techniques. These fall into the category of viscous control or stiffness control. However, for crash test it is recommended, e.g. [9], to use stiffness hourglass control, IHQ = 4, with hourglass coefficient QM = 0.03. The aim of the paper is to assess the influence of different setting of shear factor and hourglass control on the overall result of the crash test simulation. We analyze 4 cases summarized in Table 1.

| Model designation | Control cards, description, color |
|---|---|
| A | SHRF = 0.0, IHQ = 4, QM = 0.03 |
| B | SHRF = 5/6, IHQ = 4, QM = 0.03 |
| C | SHRF = 0.0, no hourglass control |
| D | SHRF = 5/6, no hourglass control |

*Table 1: Variants of control cards in simulations of crash test*

## 3 Numerical model, results

We simulate the European standard TB11 crash-test i.e. car of total mass 900 kg impacting the barrier with 100 km/h velocity at 20° angle. The barrier model corresponds to real-life steel ORSTA bridge barrier. Geo-Metro model was obtained from ROBUST project repository (http://www.vegvesen.no/s/robust/). Some corrections in control cards were introduced prior to simulations. In the subsequent figures we show the comparison of time history of: total energy (Fig. 1), kinetic energy (Fig. 2), internal energy (Fig. 3), hourglass energy in models A and B (Fig. 4) and hourglass energy in models C and D (Fig. 5). It is seen that there is among the models in kinetic energy. Concerning hourglass energy we observe substantially greater values of hourglass energy in models C and D (Fig. 5) than in models A and B. This is reflected in total energy histories as well as in internal energy histories. In particular we observe the meaningful reduction of the hourglass energy relative to the total energy. With hourglass control the hourglass energy amounts to 3E+6 while the total energy is of order of 0.55E+9. However, without the control the hourglass energy is of order of the total energy.

In Fig. 6-9 we show the selected time instance after the collision of the car with the barrier. It is visible that, in fact, we observe four different scenarios. Depending on the model the car is redirected at different way. In table 2 we show severity indices ASI and THIV along with PHD index as they vary among the models.

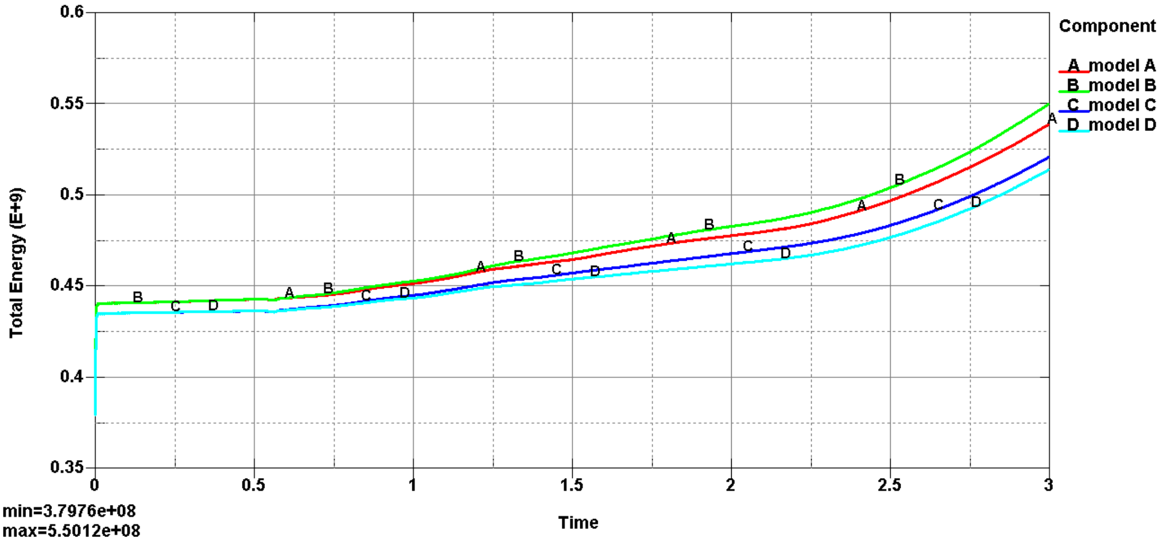


*Fig.1: Time history of total energy*

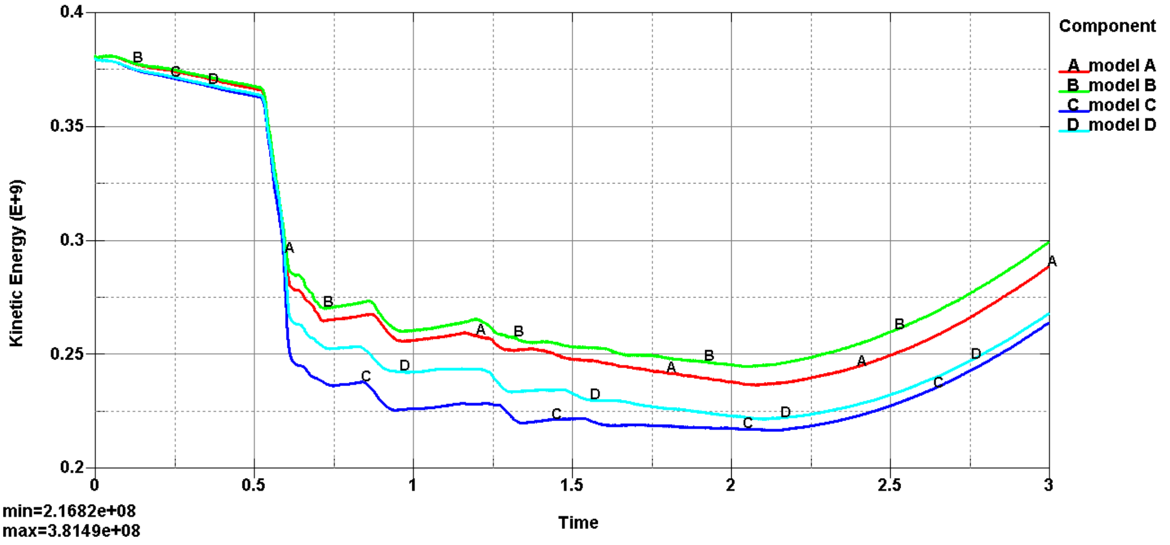


*Fig.2: Time history of kinetic energy*

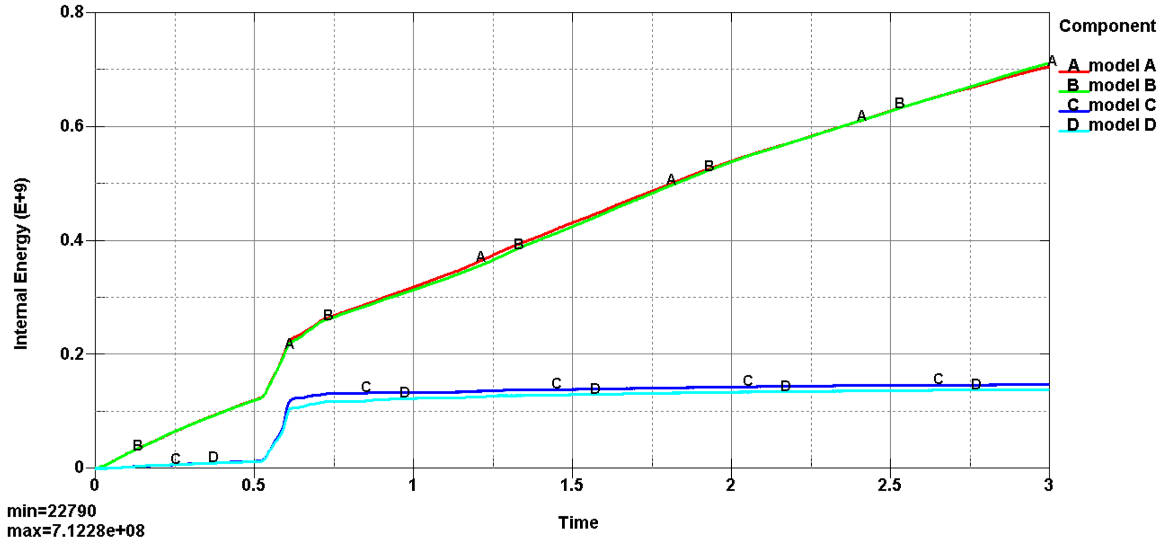


*Fig.3: Time history of internal energy*

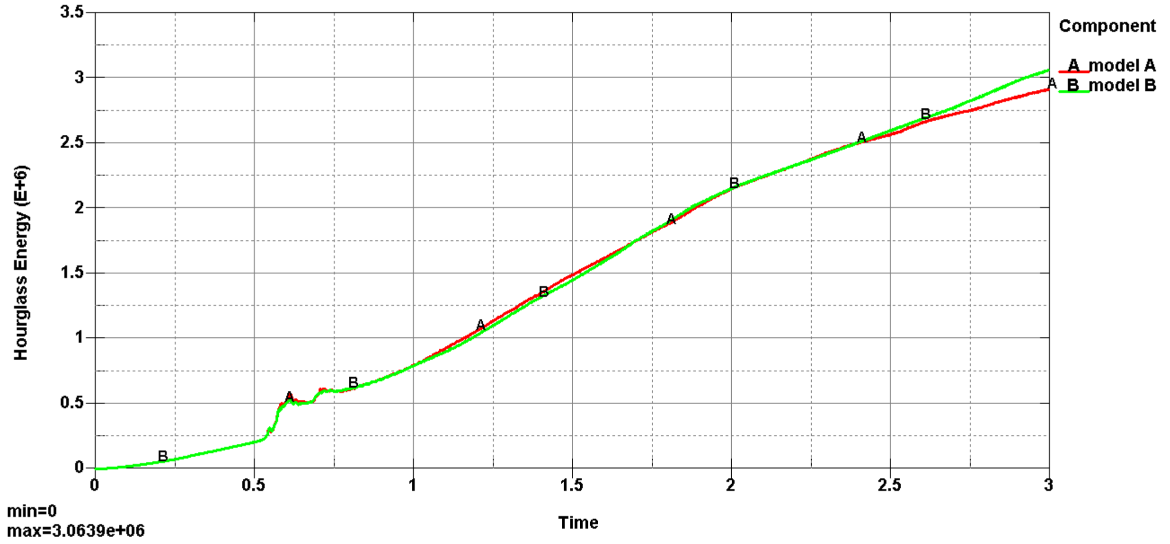

*Fig.4: Time history of hourglass energy, models A and B*

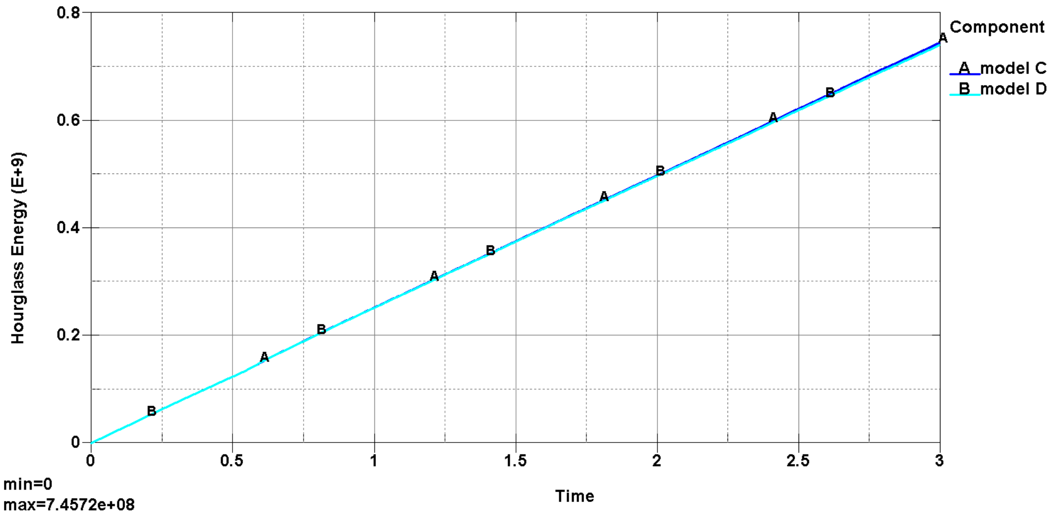


*Fig.5: Time history of hourglass energy, models C and D*

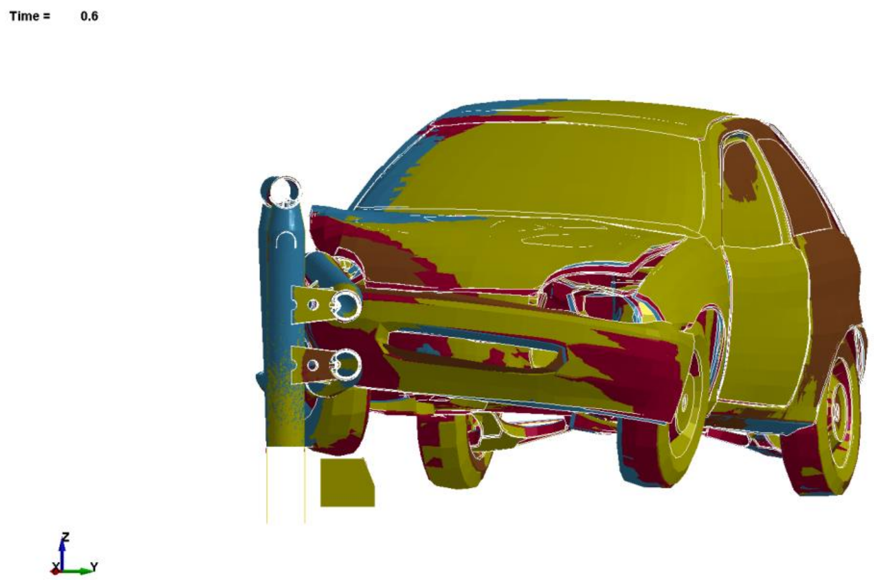


*Fig.6: Deformed configurations: model A (blue), model B (yellow), model C (brown), model D (magenta)*

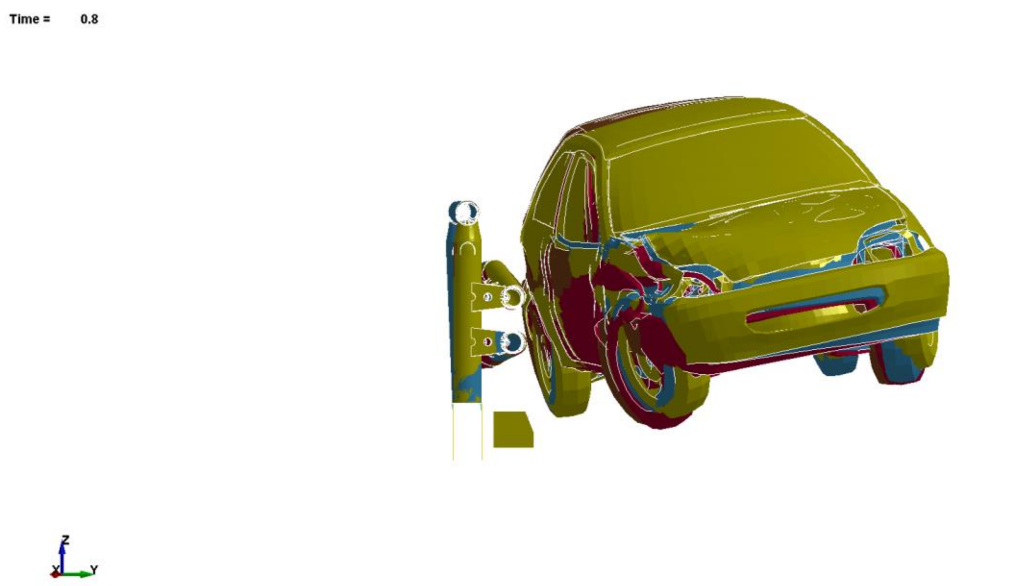


*Fig.7: Deformed configurations: model A (blue), model B (yellow), model C (brown), model D (magenta)*

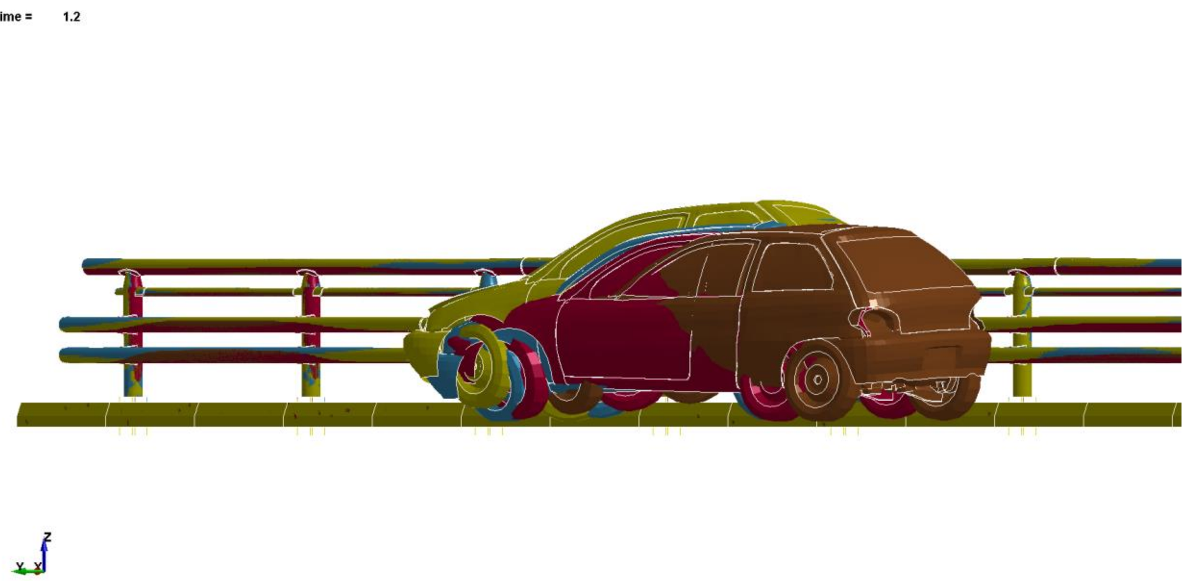


*Fig.8: Deformed configurations: model A (blue), model B (yellow), model C (brown), model D (magenta)*

| **Model designation** | **ASI, -** | **THIV, km/h** | **PHD, [g]** |
|---|---|---|---|
| A | 1,76 | 37,0 | 13,2 |
| B | 1,64 | 35,6 | 10,9 |
| C | 1,75 | 36,9 | 10,3 |
| D | 1,66 | 35,8 | 13,4 |

*Table 2: Results of TB11 tests depending on the model*

## 4 Summary

We have shown that selection of shear correction factor SHRF and proper hourglass control have influence on the results of crash test simulation. This is of importance when FEM simulation of the crash-test is used to evaluate the performance class of the safety barrier.

## 5 Acknowledgements

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## 6 Literature

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