An Investigation to Compare the Application of Shell and Solid Element Honeycomb Model in ODB

Mehrdad Asadi (m.asadi@cellbond.com)

Cellbond (a division of Encocam Ltd.)

Huntingdon, UK

Brian Walker (ARUP, UK)

Hassan Shirvani (Anglia Ruskin University, UK)

Summary:

Cellbond and ARUP have launched their advanced crash barrier models in 2006 and since the time a continuous study has been carried out to explore costumer requirements and review feedbacks. Existing barrier models are constructed using Solid element configuration in honeycomb segments along with validated Modified_Honeycomb material cards. Due to a number of demands on using Shell based honeycomb model in crash barriers by car manufacturers, it was decided to investigate the application in detail using full-scale test data.

This paper represents the methodology of creating the Shell-based ODB and the comparison with existing solid based FE model. Frontal Offset tests are carried out by a large number of test houses worldwide, according to the European regulation and to FMVSS, as well as by EuroNCAP, Australian NCAP, JNCAP and IIHS. In the frontal offset test, only one side of a vehicles front end hits the deformable barrier, which means that a more concentrated area of the vehicles structure must sustain the impact of the crash rather than the whole width of the vehicle. The Cellbond ODB barrier has been investigated which consists of two different sized aluminium honeycomb blocks in main body and bumper partially covered in aluminium skins. Number of static compressive tests performed to specify honeycomb and adhesive material characters. The barrier was subjected to four individual test conditions with different impactor and impact speeds.

Keywords:

Car Crash Test, Frontal Test, Offset Deformable Barrier, ODB, Aluminium Honeycomb, LSDYNA

1 Introduction

The Offset Deformable Barrier (ODB) is designed to represent the characteristics of a vehicle's front end. Based on the various tests, the barrier responds differently depending on the front end design and the size of an impacting vehicle [1]. The complex failure mode of the deformable barrier makes it very difficult to simulate using the available finite element material model. The Offset Deformable Barrier (ODB) has been used by Euro NCAP and most of leading car manufacturers and test houses worldwide. This deformable barrier is used for frontal offset impact tests and its specifications have been developed by EEVC Working Group (WG) 11. The specifications for ODB barrier are also recognized by a number of other standards and regulations such as ECE R94 [2] that specifies a barrier which includes a crushable face to simulate the stiffness of the front end of a striking vehicle. The barrier is also accepted by FMVSS 208 (Federal Motor Vehicle Standards) Occupant Crash Protection.

The main block of the ODB (Figure 1) is constructed from aluminum honeycomb with crush strength of 0.34 MPa (50 psi) ± 10%. The foil thickness is approximately 0.076 mm and honeycomb cell size should be based on 19.1 mm ± 20% to achieve 28.6 kg/m3 density. The main block is 650 mm long, 1000 mm wide (crash face) and 450 mm deep (crash depth). The bumper is made of three individual but identical honeycomb blocks which are sandwiched between 3.02 mm (0.125”) thick aluminum plates. The crush strength of honeycomb blocks is maintained at 1.69 MPa (250 psi) ± 10% in bumper parts. The part dimensions are 330 mm x 1000 mm x 90 mm (L, W and D respectively). The connectivity between individual parts is created using specific Polyurethane adhesive. The glue is evenly spread on skin surface and the bond strength is then obtained by supplemental heal and pressure on the structural set. The overall mass of the barrier is approximately 20 kg and includes the weight of main honeycomb block, three bumper honeycomb sections, backing plate, claddings and adhesive. To mount the barrier on rigid blockade (for crash test), a number of holes are allocated on edges of backing plate. A summary of material data and dimensions are given in figure 1.

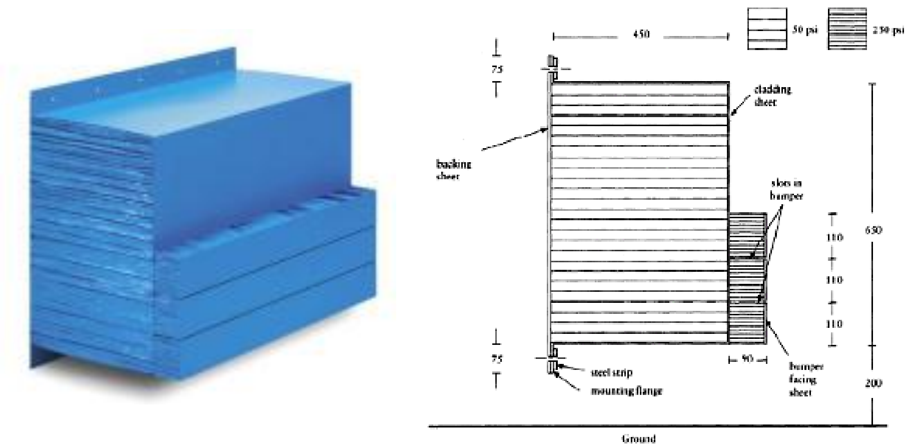


Figure 1. ODB Barrier General Dimensions

2 FE model creation

Cellbond and ARUP have launched advanced finite element models for full-range of crash test barriers in 2006. The models are generated for LSDYNA users. Our previous publication [3], demonstrates the development and validation process of the ODB FE model in which the aluminium honeycomb have been generated applying Solid elements to parts. Due to a number of demands on using Shell based honeycomb model in crash barriers by car manufacturers [4], a study was undertaken to investigate the application of Shell elements in test crash barriers. This paper represents the approach for the ODB.

A research program by Cellbond has shown that a simplified generic model can be used to simulate crush behaviour of the aluminium honeycomb using shell elements [5]. Because of the geometrical symmetry of honeycomb structure, a Y shape cross-section is chosen in this method to represent a block of structure with reasonably large dimensions in plan (Figure 2). In reality, there is a thin layer of glue between foils (0.002 mm), however, to bring more simplicity into the model, it has been ignored. Graph 1, compares the numerical outcome with corresponding average results from experimental tests. It can be seen that despite the simplicity of the new model, it represents a good accuracy to estimate the crush strength and there is a close correlation between test output and CAE results.

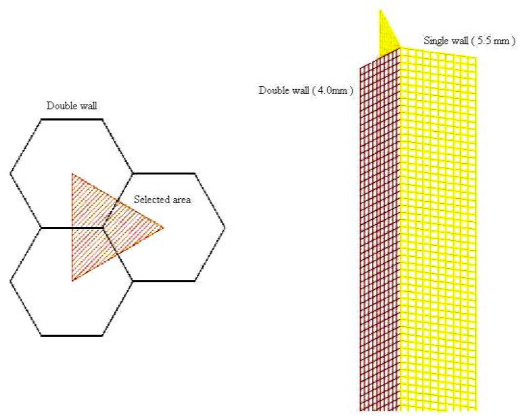
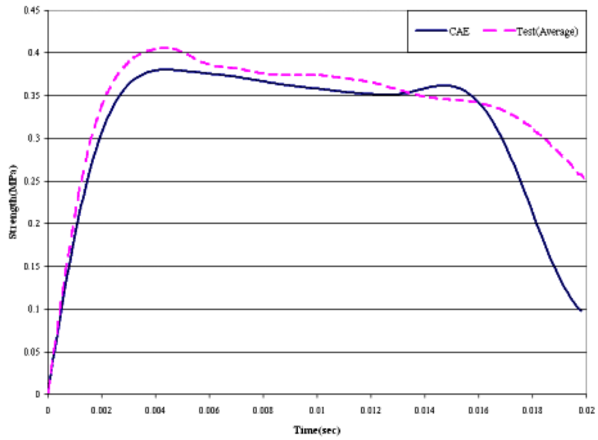


Figure 2. FE model for honeycomb



Graph 1. CAE vs. Test, Filtered CFC 60

2.1.1 Generalizing the method into new ODB model

The new ODB FE model has been created using LSDYNA where Shell elements configure the main honeycomb sections. However, to reduce the number of nodes and elements and increase cost efficiency of the model, cell sizes are assigned larger than real honeycomb geometry (see figure 3). To reduce the analysis time, cell sizes are increased to 52mm in the model whereas they are 19.1mm in physical barrier. To recover structural stiffness of the part, material thickness is amended according to the cell size relation. Verified material properties [5] are employed to define the characteristics in the Modified_Piecewise_Linear_Plasticity material model (Mat_123) which is implemented in main honeycomb section. It was observed in Solid-based ODB FE model (also experimental tests) that due to the substantial rigidity compare to main honeycomb in bumper segments, the deformation occurs mainly in bending modes [3]. Therefore, bumper beams have been modelled using Solid element along with Modified Honeycomb material card (Mat_126). Consequently, the Yielding –Surface technique describes the crush strength of the bumper in material model (Equation 1)

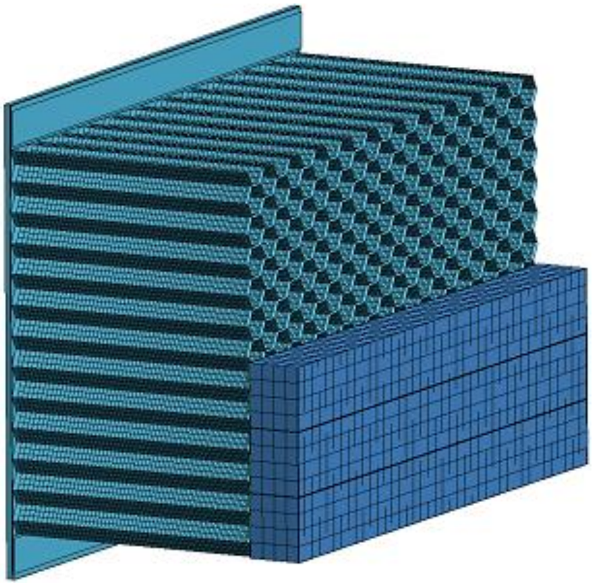
$$\sigma^{y}(\varphi,\varepsilon^{vol}) = \sigma^{b}(\varphi) + (\cos\varphi)^{2}\sigma^{s}(\varepsilon^{vol}) + (\sin\varphi)^{2}\sigma^{w}(\varepsilon^{vol}) \tag{1}$$

where:

φ = Section angle with the strong axis (see [3] for more details)

$\sigma^{b}(\varphi)$ = Yield stress as a tabulated function of section angle

$\sigma^{s/w}(\varepsilon^{vol})$ = Stiffness as a tabulated function of volumetric strain



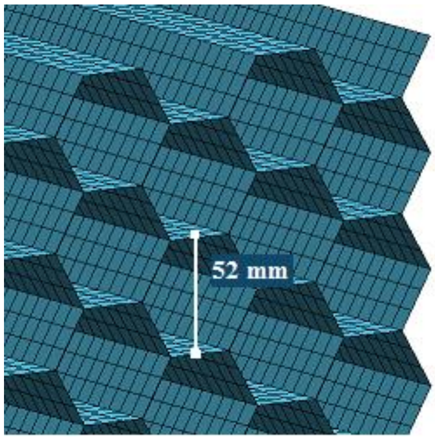


Figure 3. The new ODB shell model.

3 Evaluation tests

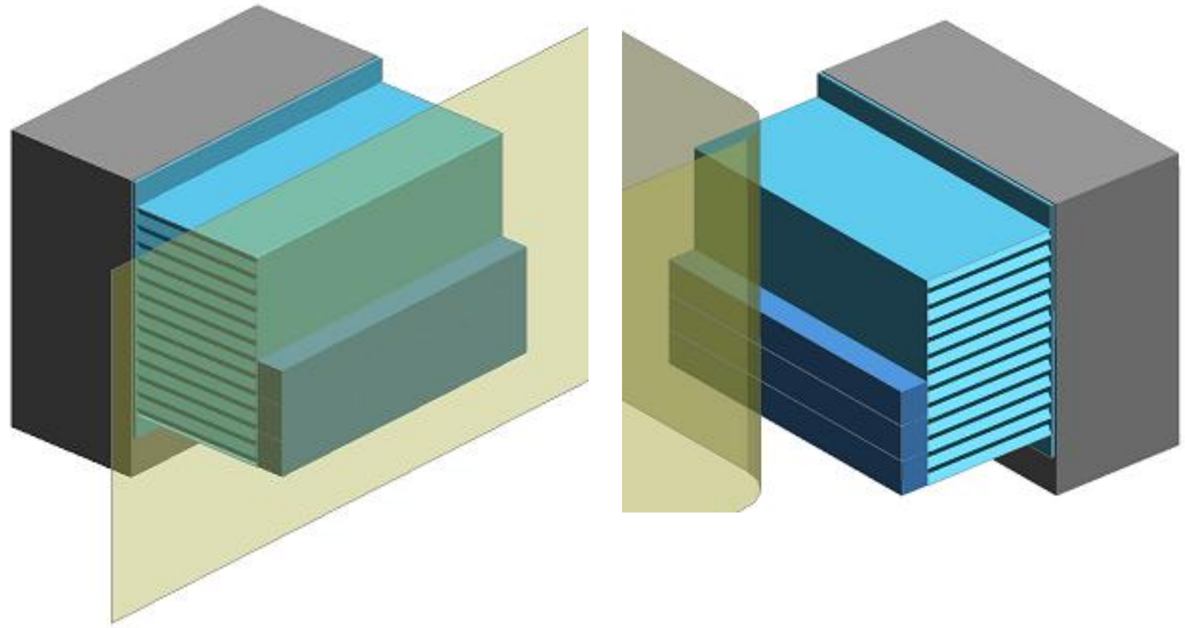
To validate the model and examine the accuracy of assumptions and defined parameters, it has been subjected to a number of experimental dynamic tests. In the evaluation tests, the barrier is mounted on a rigid surface with constraining two end edges against the blockade. Four different test impactors have been designed to assess crash performance of the new barrier model. The test configurations have been chosen in a way to simulate the barrier behaviour during car crash tests and examine generated model components under different loading conditions.

The Rigid-Wall test configuration (Figure 4a) is proposed to assess the normal (horizontal) crash performance of the new ODB finite element model. In this test the barrier is fixed on a static wall and is subjected to a moving flat impactor. The impactor trolley mass is 1354 kg in Rigid-Wall test while the average test speed has been maintained at 8.23 m/sec (29.62 kph). The Half-Wall an offset (50% overlap) impacting the ODB crash test barrier (Figure 4b) and represents normal and shear performance of the ODB and examines the correctness of new model in terms of compatibilities for such deformations. In this experiment, the barrier is fixed against rigid wall and constrained at all degrees of freedom. The overall impactor mass is 1156 kg and the average test speed has been maintained at 8.64 m/sec (31.1 kph).

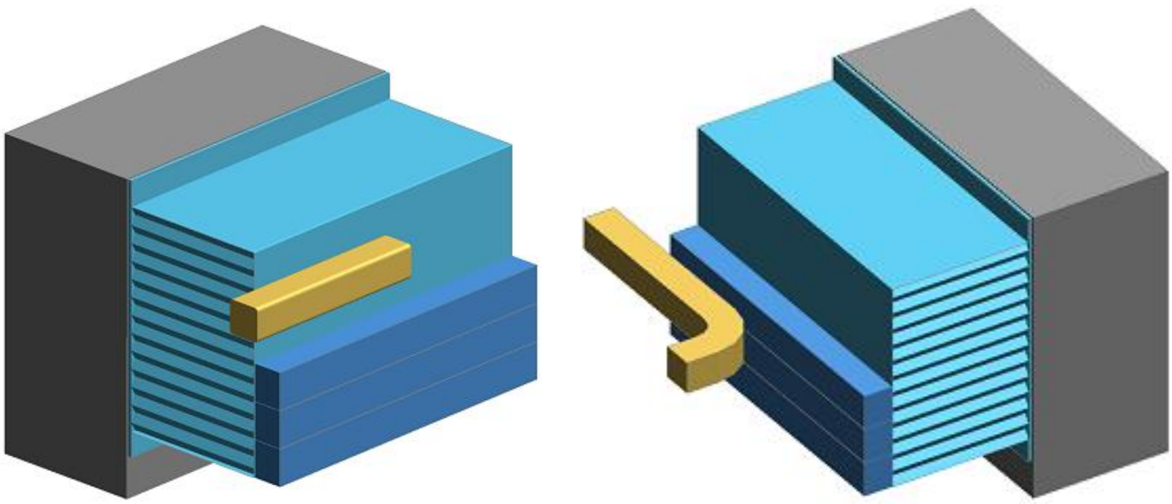
The High-Horizontal Bar test involves a horizontal bar (50% overlap) impacting the upper section of the barrier efficiently on main body area of the ODB crash test barrier (Figure 4c). This test represents mostly the shear and piercing performance of the ODB and assesses the accuracy of new finite element model for sudden local impacts and consequently major penetrations. The overall impactor mass is 1354 kg and the average applied test speed has been measured at 8.08 m/sec (29.1 kph).

Figure 4d, shows the general configuration of the Low-Horizontal Bar test in which a horizontal impactor hits two upper sections in bumper part (50% overlap). The test is designed to observe piercing performance of the main honeycomb section when the bumper is suddenly pushed into it. The overall mass of the impactor is 1215 kg in this test and average test speed has been maintained at

8.43 m/sec (30.3 kph). Load-cell data is obtained from individual sensor behind the blockade and acceleration has also been measured by accelerometers allocated at the COG of the moving trolley. For model verification, however, load-cell data are used.



a) Flat-Wall test *b) Half-Wall test*

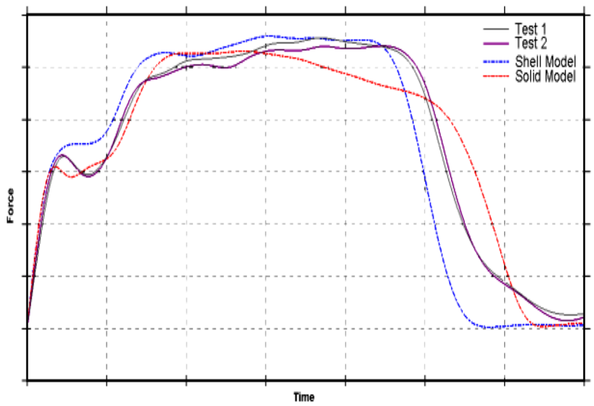


c) High-Horizontal Bar test *d) Low-Horizontal Bar test*

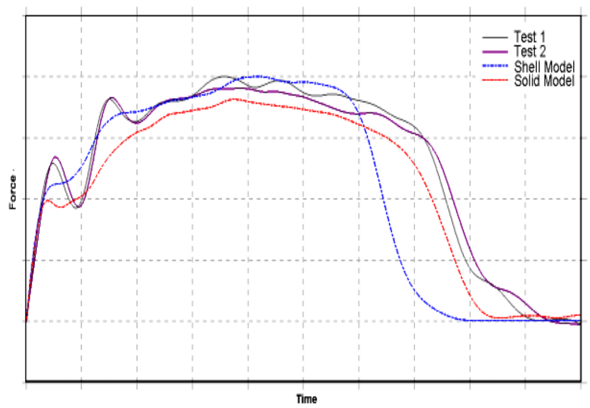
Figure 4. Experimental test configurations

4 Model correlation implementing experimental test data

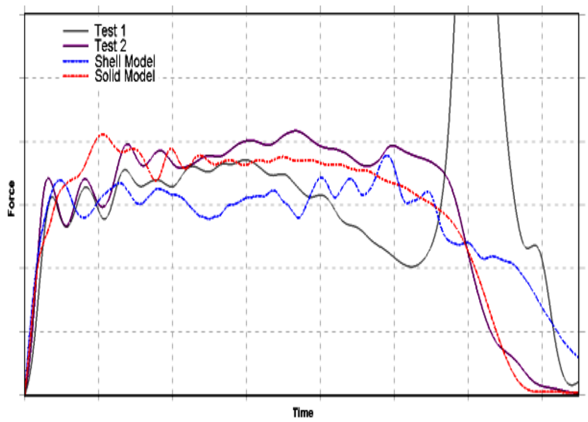
Graphs 2(a-d) show the comparison between test results, Solid and Shell FE model analysis. Results for the Solid-element based ODB model are carried out from our previous publication [3]. The evaluation is based on force magnitude on blockade versus time in all test configurations. The model with Shell elements in main honeycomb part, offers a closer data to experimental results in majority of test cases compared to outputs from Solid element honeycomb model. The Solid model, however, shows better correlation in terms of crash time observation and also results in High-Horizontal test. In Low-Horizontal test, the Shell model represents higher accuracy, although, test data are not substantially consistent in this test. Deformed barriers are compared in figures 5(a-d). The new model presents precise deformation modes in all test conditions compared to physical tests and corresponding Solid-based FE models. The results in Low-Horizontal FE analysis appeared closer to the test in new model. The analysis time, however, is considerably high in new model. The average solution time in Shell model is (3:46 hrs) whereas it runs at (56 minutes) in Solid model. This is while the timestep is set equal at both analysis cases (DT2MS = - 1.33E-6) and same system solves the models.



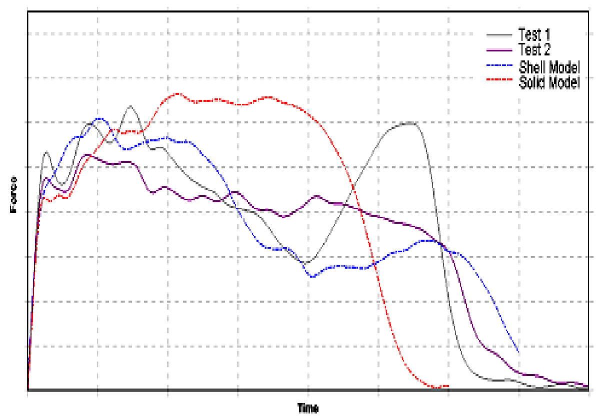
a) Flat-Wall test



b) Half-Wall test

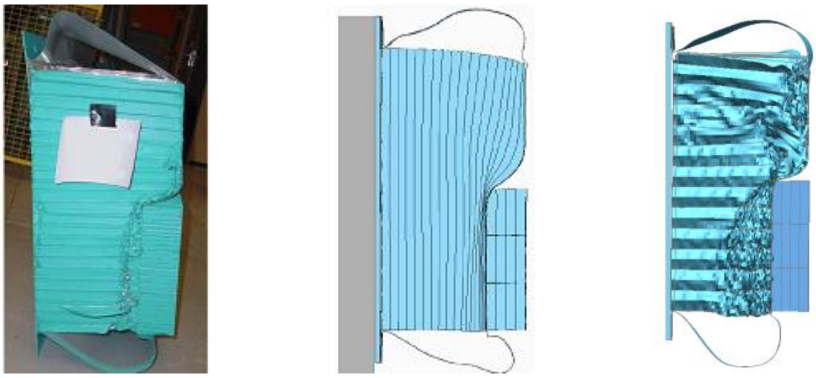


c) High-Horizontal Bar test



d) Low-Horizontal Bar test

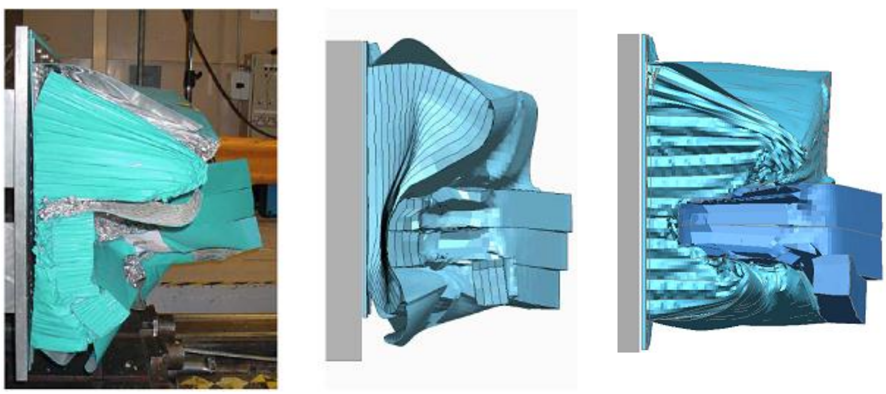
Graph 2. Crush test results CAE vs. Test, Filtered CFC 60



a) Flat-Wall test

b) Half-Wall test

c) High-Horizontal Bar test



d) Low-Horizontal Bar test

Figure 5. Comparison of deformed barriers (Test – Solid model – Shell model)

5 Conclusion

The new finite element model for the ODB crash test barrier has shown precise accuracy in all evaluation tests in existing stage of this study. Shell-based honeycomb model represents realistic performances in numerical data as well as deformed patterns in barriers. Although, larger cell sizes have configured the main honeycomb part in new ODB model and clearly this does not reflect the real geometry in physical barrier, the effect of such changes is eased down to minimum through other realistic inputs i.e. modified foil thickness. A remarkable disadvantage of existing model is the higher analysis time compared to the model with solid elements in honeycomb components. The solution time is approximately four times longer in this model which adds a notable cost on the design process.

6 Literature

[1] Tau T., Chi-Chin W., Sharath V., Finite element simulation of the EEVC offset deformable barrier, 10th International Conference on Vehicle Structural Mechanics and CAE, USA, 1997

[2] ECE R94 Revision 1, Frontal Impact Protection, May 2007

[3] Asadi M., Walker B., Shirvani H., Development of the Advanced Finite Element Model for ODB Impact Barrier, LSDYNA User Conference, Japan, 2008

[4] Kojima S., Yasuki T., Application of Shell Honeycomb Model to IIHS MDB Model, 6th European LS-DYNA Conference, Sweden, 2006

[5] M. Asadi, H. Shirvani, E. Sanaei, M. Ashmead, A Simplified Model to Simulate Crash Behavior of Aluminum Honeycomb, International conference on Advanced Design and Manufacture, China, 2000