The 3rd Generation Crash Barrier Modeling Method and Application on MPDB

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1 Challenges of strong barrier to car crash simulation

As the car crash protocol evolves, crash barrier becomes stronger and stronger, Figure 1 shows the deformation comparison of frontal barrier ODB and MPDB, side barrier EU-MDB and IIHS-Side after crashing with a compact SUV, ODB bottoms out while MPDB has half depth left, EU-MDB has very large deformation while most part of IIHS-Side barrier even does not deform.

(a) ODB *(b) MPDB* *(c) EU-MDB* *(d) IIHS-Side*

Fig.1: Deformation comparison between weak and strong barrier

Strong barrier brings new challenges to FEM crash simulation, take the frontal crash for example: ODB, designed in 1990s, has much lower crushing strength than modern designed car, ODB bottoms out even in crashing with supermini Smart-Fortwo [1]. In most crash tests, car body longitudinal beam will not deform until it bottoms out ODB and hits the rigid wall behind, in this test scenario, ODB has little influence on the final deformation of car body, accordingly computer crash simulation does not need highly accurate ODB finite element model.

MPDB, the new frontal barrier which is going to be used by EURO-NCAP from 2020, is a very strong barrier, its crushing strength is equal to or higher than car body. EURO-NCAP requires that test car should not bottom out MPDB, otherwise -2 points penalty will be applied [2], so car body must finish its deformation during crash with MPDB, this is very different from ODB test scenario, the accuracy of MPDB model will have the same importance as the accuracy of car model.

Safety engineers need accurate barrier FEM models to win this new challenge due to test protocol update, however, the existing 1st (solid) and 2nd (big cell) generation barrier modelling methods did too much simplification on aluminum honeycomb structure, cannot be used to build highly accurate barrier model. This paper describes a new method of modelling aluminum honeycomb barrier, MPDB and PDB model were built using his method, and their deformation accuracy was verified.

2 The 1G, 2G and 3G barrier FEM models

Crash barrier is mainly composed of various types of aluminum honeycomb which is a hexagonal cellular structure. Aluminum honeycomb's cell wall is very thin, its thickness generally less than 0.1 mm, so the cell wall is very easy to be folded and teared, its tearing strength is similar as coated paper. Both weak cell wall and hexagonal cellular structure form a unique deformation mode of aluminum honeycomb [3]. How to model the barrier is a long-standing problem for the industry, direct meshing the barrier will end up with hundreds of millions of elements and unpractically small time-step, so all barrier modeling methods need to simplify aluminum honeycomb structure, depending on the model's accuracy and number of retained aluminum honeycomb features, the barrier FEM models can be divided into three generations, their main differences are shown in Table 1.

	1G	**2G**	**3G**
Element Type	solid	shell	shell

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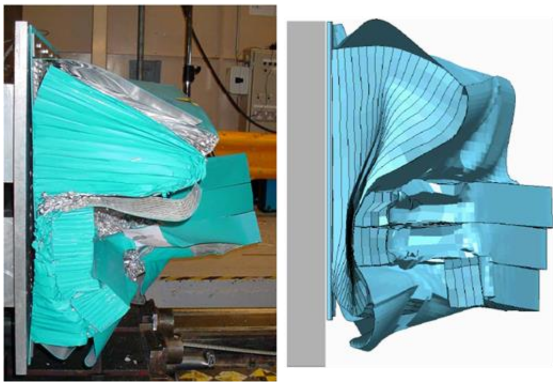
Retained aluminum honeycomb features	Hexagonal Cellular Structure	x	√	√
	Cell Size	x	x	√
	Cell Wall Thickness	x	x	√
	Cell Wall Tearing Strength	x	x	√
Accuracy		Low	Normal	High
Coputing Time		Low	Normal	Similar as 2G

Table 1: Barrier FEM modeling differences between generations

2.1 1G barrier model

The 1st generation barrier modeling method uses solid element to model aluminum honeycomb, the basic idea of this method is treating aluminum honeycomb as a continuous material instead of a hexagonal cellular structure, it is a complete simplification of the structure, as a result, 1G barrier model's deformation mode is quite different from hardware, Figure 2b shows the 1G solid barrier model's deformation after impacted by offset beam, the whole barrier model is flowing in transverse directions, this kind of deformation never happen on hardware (Figure 2a), and large deformed solid elements make the model computationally unstable. The reason why solid element cannot be used to model barrier is well explained in a paper written by Toyota [4]. The only advantage of 1G barrier model is its short computing time, but with the rapid development of cluster computer, 1G barrier FEM models were basically abandoned by the industry.



(a) ODB hardware (b) 1G ODB model

Fig.2: 1G ODB model deformation comparing to hardware (pictures from Arup website)

2.2 2G barrier model

The 2nd generation barrier modeling method uses standard shell element to model aluminum honeycomb, the honeycomb cell size is largely increased in order to control the total element number and time step within practical range, so visually 2G barrier model has hexagonal cellular structure, but the whole barrier model only has a few rows of hexagonal cells which is very different from hardware, the model's total cell number is only about 5% of hardware on strong honeycomb blocks, such as bumper beams of side barriers and middle block of MPDB, because the cell size of these blocks is only 6.4mm or 9.5mm [5, 6], corresponding 2G barrier models need larger cell size scale factor to reduce element number. There are another two main invisible difference between 2G barrier model and hardware: cell wall thickness and tearing strength, 2G barrier model's cell wall thickness must be increased to maintain honeycomb axial crush strength, and its cell wall tearing strength is much higher than hardware because of the nature of big standard shell element. But with retained hexagonal cellular structure, 2G barrier models have improvements on deformation accuracy and numerical stability than 1G models, together with significantly increased computing time, 2G models became the main stream solution to barrier modeling around 2006.

The main problem of 2G barrier is structural instability. Figure 3a shows EU-MDB deformation after crashing with car, aluminum honeycomb cells keep straight, deformation is localized in the front area, whole barrier structure is stable. The structural stability of aluminum honeycomb is the result of both large number of hexagonal cells and weak cell wall, high density hexagonal cells makes aluminum honeycomb having high shear stiffness in transverse directions; thin and weak cell wall tends to fold and tear instead of bend when being impacted, so the aluminum honeycomb's deformation can be localized.

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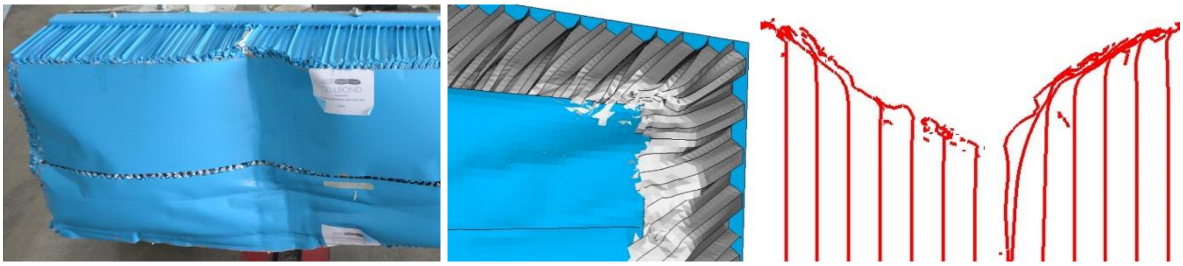
But the 2G barrier models go to the opposite side of the essence of aluminum honeycomb structure, they only have less than 10% total cell number of hardware and much thicker cell wall which is hard to be teared, so when the FE model cells are impacted, strong cell wall tends to bend instead of fold or tear. Figure 3b/c shows the 2G EU-MDB model's deformation, cells contacting with car B/C pillars are bended, model is not structurally stable. 2G barrier modeling method can not give up limiting element number to have smaller cell size, due to the time step (need big enough shell) and 3-shells per edge constraints.

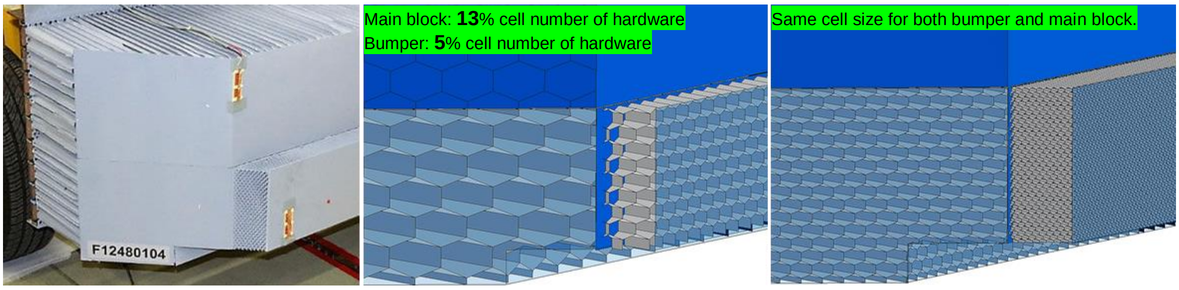


(a) EU-MDB deformation (b) 2G model (c) 2G model cross section

Fig.3: 2G barrier model structurally instable

2.3 3G barrier models

3G barrier models use specially designed shell element to model aluminum honeycomb, keeping hexagonal cellular structure, cell size, cell wall thickness and tearing strength same as hardware, having same structure as hardware is the main difference between 3G and 2G model (Figure 4). With all these important aluminum honeycomb features retained, 3G model's accuracy is greatly improved. The 3G barrier model has very large element number, but with the simplified shell element and material model, its computing time is equivalent to or slightly longer than 2G model, the difference can be neglected when integrated with car model for crash simulation.

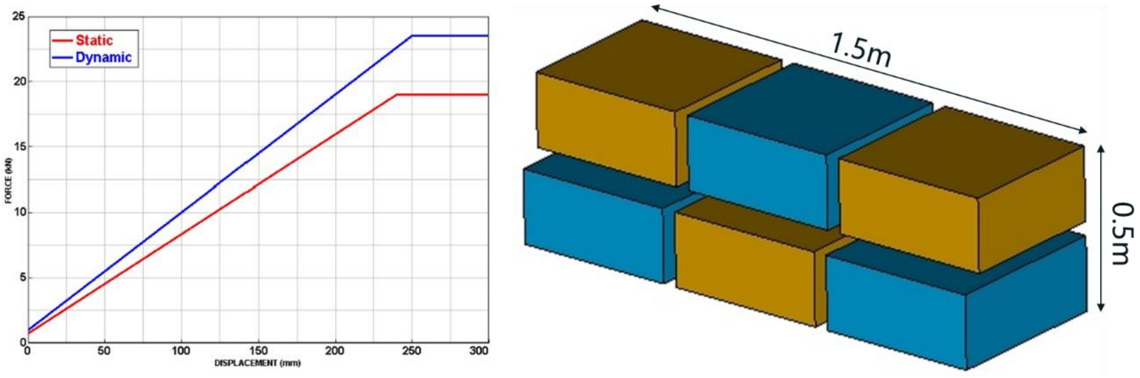


(a) AE-MDB (b) 2G model (c) 3G model

Fig.4: Model detail comparing between AE-MDB hardware, 2G model and 3G model

2.4 Air effect

The air trapped inside barrier will be compressed and ventilated during crash test within 0.1 second, which cause the barrier having strong dynamic effect, Figure 5a shows the middle lines of EU-MDB block-4 static and dynamic strength corridor [7], dynamic strength is over 20% higher than static under the condition that EU-MDB back plate has ventilation holes designed. For frontal barriers without ventilation holes, like ODB and MPDB, the air effect is even more important. 1G and 2G barrier model usually use large airbags to model the air effect, or just adding strength to the solid or shell element, Figure 5b shows the 6 big airbags in a 2G EU-MDB model, this solution is acceptable on side barrier, because the contacting surface between car and side barrier is large and generally continuous, but it is not working for frontal barrier like MPDB, the frontal contacting surface is smaller and un-continuous. In 3G barrier model, the air effect is modelled by thousands of beams to make sure the air force is spreading rightly on the car body.



(a) EU-MDB block-4 strength *(b) 6 airbags in a 2G EU-MDB model*

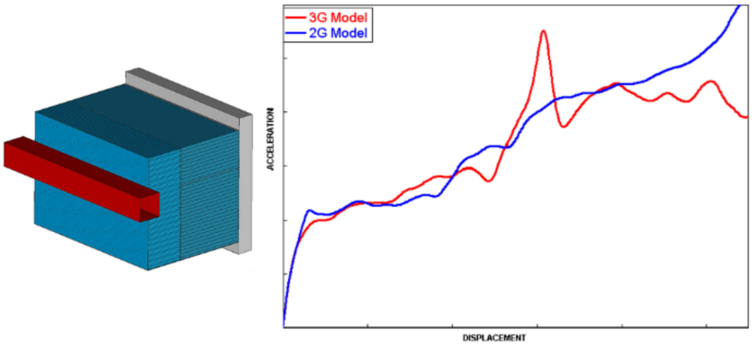
Fig.5: Air effect in EU-MDB and 6 airbags in 2G barrier model

3 Validation of 3G barrier models

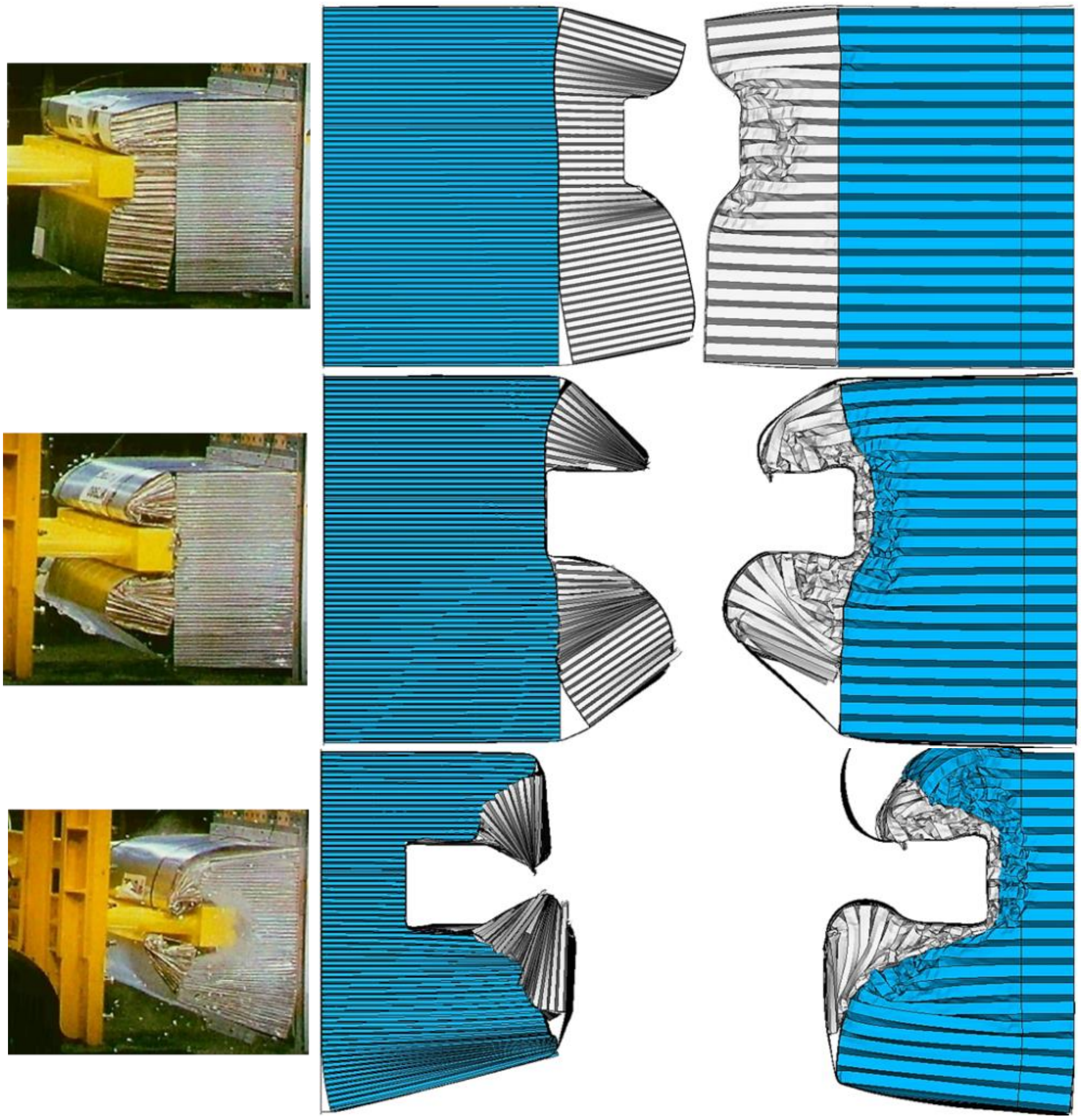
MPDB [6] and PDB [9] models were built using 3rd generation barrier modeling method, rigid cross beam impacting PDB and rigid tubular impacting MPDB simulation were performed, simulation results were compared with test and 2G barrier model.

3.1 Cross beam impact PDB

Figure 6 shows the test and simulation results of rigid cross beam impact PDB, 3G model's deformation is well correlated with test. With the impact of the beam, the front honeycomb block of PDB is split into 3 parts in both hardware and 3G model, but in 2G model the front block is not split but pulls the entire barrier to collapse inward due to its large strong cell wall. Although 2G model is structurally unstable, its deformation resistance force (Figure 6b) is even higher than that of 3G model, from the deformation shape, we can conclude that hardware and 3G barrier model's resistance force mainly coming from honeycomb cells crushing, 2G model's resistance force mainly coming from dragging larger area of barrier structure.



(a) test setup *(b) impactor acceleration curve*

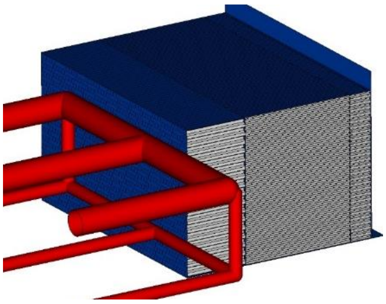


(c) test *(d) 3G model* *(e) 2G model*

Fig.6: Cross beam impacting PDB

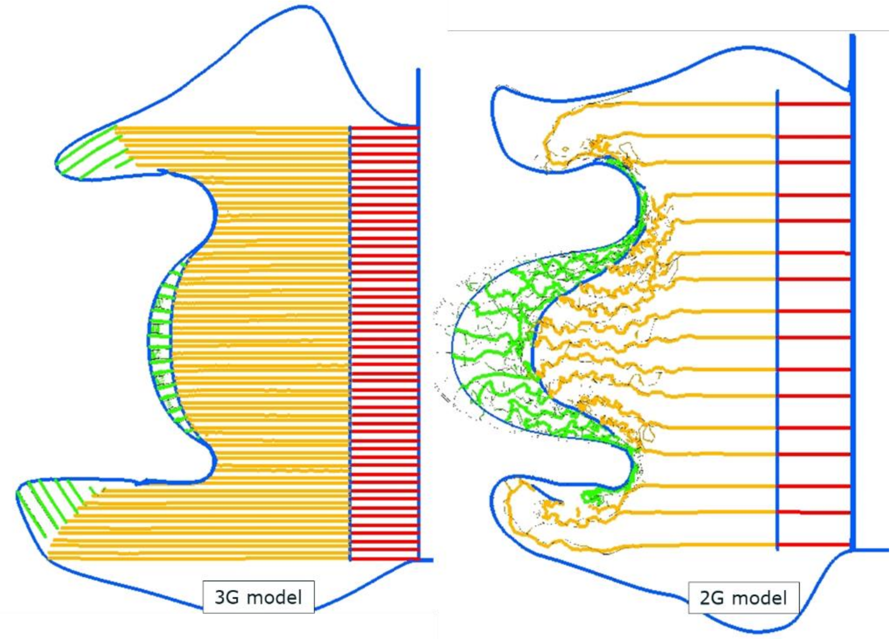
3.2 Tubular impact MPDB

Figure 7 shows the test and simulation results of a rigid tubular impacting MPDB, using test setup specified in EU-NCAP barrier specification [6]. The hardware barrier deformation shows that the barrier is a very stable structure, non-crushed area remains undeformed, the left part of front block-C is squeezed out by tubular, 3G model well reproduces this deformation phenomena. On the contrary, in 2G model result, the left part of front block-C is still liked with covers, and structural instability happened on most part of barrier.

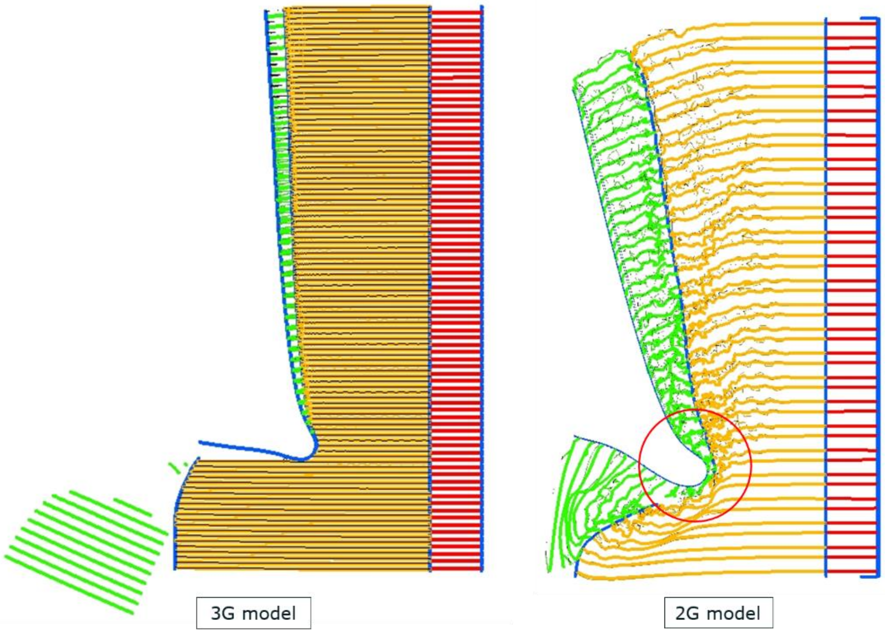


(a) test setup

(b) 3G model *(c) test[9]* *(d) 2G model*



(e) YZ Cross Section



(f) XY Cross Section

Fig.7: Tublar impacting MPDB

Figure 7(e) (f) show the cross-section comparison between 2G and 3G models, in 2G model, the weaker frontal block is not compacting and not split, the whole barrier is structurally unstable in deformation area. It also can be concluded that the highest force is happening in the circled area, the side vertical tube is shearing the whole barrier. Of course, the 2G model can be tuned to meet the total force corridor, but the model force is the result of wrong barrier deformation, and deformation mode is important for MPDB, it is part of the assessment protocol.

4 Summary

In this paper, 1st and 2nd generation crash barrier modeling methods are reviewed, the new 3rd generation barrier modeling method has been successfully developed. This new method was applied to MPDB and PDB modeling, two simulations against test were performed, simulation result verified that 3G barrier models are well correlated with hardware barrier deformation mode.

5 Literature

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