Development of Researched Moving Deformable Barrier (RMDB) FE model for Oblique Crash Test

Nobuhisa Ishiyama, Shinobu Tanaka, Satoshi Fukushima, Tsuyoshi Yasuki
Toyota Motor Corporation

Masahiro Saito
Toyota Technical Development Corporation

Jesse Buehler, Brian Tew
Toyota Motor Engineering & Manufacturing North America

Abstract

This paper describes a finite element model for a Researched Moving Deformable Barrier (RMDB) that simulates an oblique crash test. National Highway Traffic Safety (NHTSA) is currently conducting research on oblique RMDB-to-Vehicle (Oblique) testing. The RMDB, which consists of an aluminum honeycomb and an outer cladding sheet, exhibited two deformation features after the oblique crash test. The first was cracks observed on the outer cladding sheet. The second was compressive deformation, mainly observed on the 0.724MPa aluminum honeycomb.

The RMDB FE model was developed based on the SAE paper. The aluminum honeycomb had two layers with different stiffness and was modeled by shell element to capture compressive deformation. The outer cladding sheet was modeled by tied overlapping shell elements, in order to simulate crack propagation.

The RMDB FE model was validated through the impactor test and the full car test. The results of the analyses using the model closely matched to the test results. The impactor model was developed to conduct impactor component testing. The aluminum honeycomb was glued to the jig and the impactor crashed into the aluminum honeycomb. The resulting fracture line on the outer cladding sheet and impactor acceleration data was correlated to test. Next, full car testing was performed refer to the SAE paper. The RMDB and car kinematics, velocity, structure deformation, and body intrusions largely matched to those from test. Cracks, generally corresponding to those in the test, were observed from analysis result in the outer cladding sheet. The aluminum honeycomb compressive deformation was also close to the test deformation result.

Investigation of the effects of crack propagation in the outer cladding sheet revealed that deformation in the upper aluminum honeycomb showed difference depending on whether the outer cladding sheet had cracks ore not. Thus, reproducing the outer cladding sheet cracks is effective in simulating RMDB deformation.

1. Introduction

Small overlap and oblique crashes account for 24% of all fatal frontal crashes in the United Sates [1]. This has led the National Highway Traffic Safety (NHTSA) to focus their research plan in oblique crashes for 2011-2013 on occupant safety [2], and to conduct research on oblique RMDB-to-Vehicle (Oblique) testing [3]. This Oblique test configuration is shown in Figure 1.

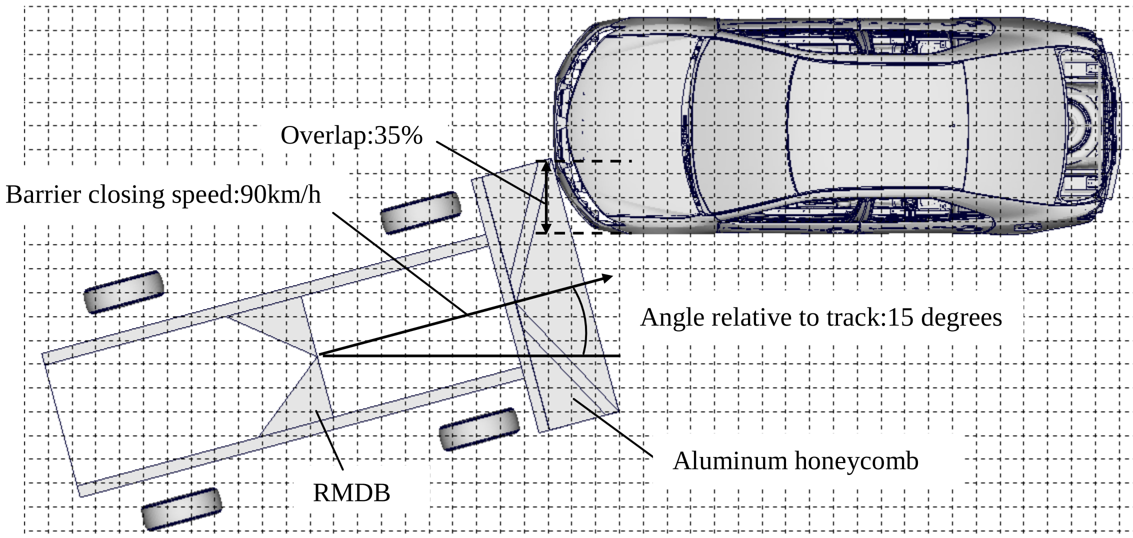


Figure 1. NHTSA Oblique RMDB-to-Vehicle test configuration.

Recently, Finite Element Method (FEM) has been widely used for crash safety development in automotive industry, because it enables detailed analysis of deformation and structural loads, and allows efficient vehicle development. This makes it important to accurately represent vehicle deformation and occupant kinematics, both of which are significantly influenced by barrier deformation.

This paper describes development of an RMDB FE model and its validation using test data.

1.2 Deformation of RMDB after an Oblique Test

The deformation of the RMDB aluminum honeycomb after an oblique crash test is shown in Figure 2. There were two noticeable features in this honeycomb deformation. First, 4 cracks were observed on the outer cladding sheet at the sheet boundary (#a), the radiator support edge (#b), the bumper reinforcement edge (#c), and the wheel outer rim edge (#d). Second, compressive deformation was mainly observed from the 0.724MPa aluminum honeycomb.

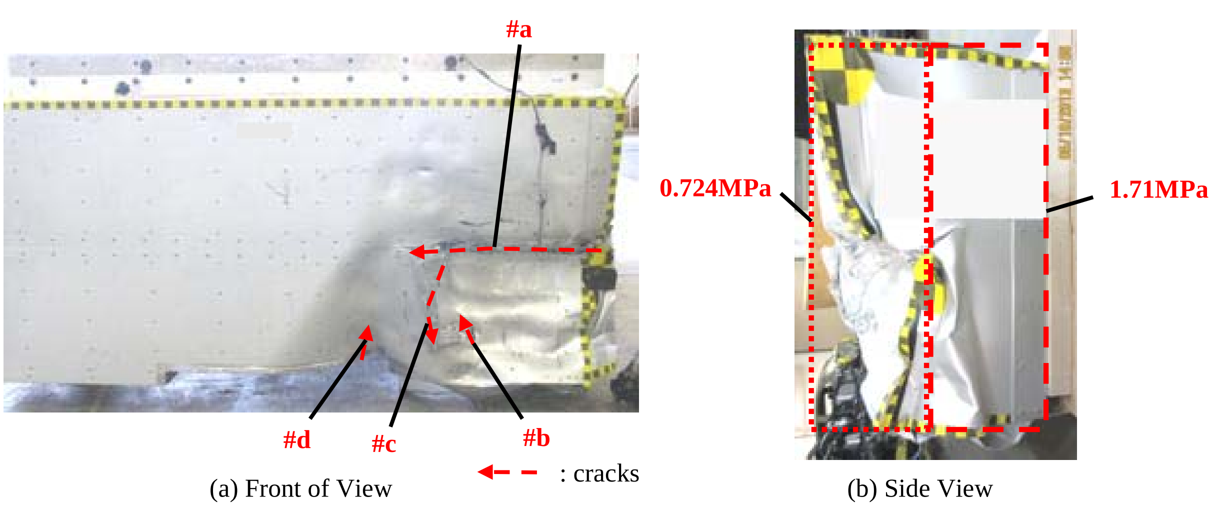


Figure 2. Deformation of RMDB.

2. Objective

The objective of this study can be represented as follows,

(1) To develop an RMDB FE model for oblique crash tests.

(2) To Validate the RMDB FE model by comparing it with both test results from impactor and full car test.

LS-DYNA Ver.971, the nonlinear dynamic analysis solver was used for this study.

3. Method

3.1 FE model of RMDB

Dimensions of the RMDB FE model are shown in Figure 3. It is developed based on the RMDB SAE paper [3]. All dimensions are in millimeter. Aluminum honeycomb was composed of two layers, which have different stiffness. Actual RMDB had suspension for stability of crash attitude. Since crash attitude of FE model was stable, it was omitted from the FE model. The number of elements, which used in RMDB FE model, was 3 million.

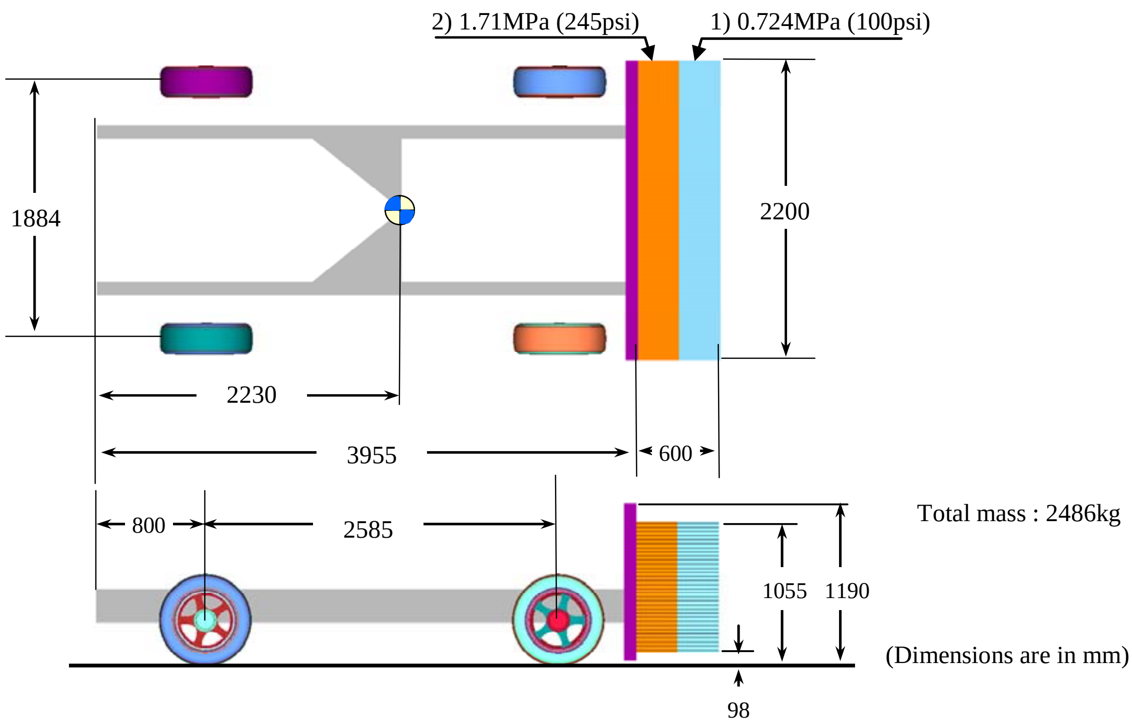


Figure 3. Dimensions of the RMDB FE model.

Two modeling techniques, aluminum honeycomb shell model and tied overlapping shell model, were used to prepare RMDB FE model. The aluminum honeycomb model using shell elements, developed by Kojima et al., allowed crash test simulations to capture shear deformation, and improved vehicle deformation correlation [4]. The modeling method using tied overlapping shell technique to represent crack propagation, which had been applied for windshield glass and established by Chikazawa et al, was used to prepare the aluminum honeycomb model [5].

In this study, both of two modeling techniques were applied to develop the aluminum honeycomb model as Figure 4. Aluminum Honeycomb was modeled by shell element to capture compressive deformation accurately. The outer cladding sheet was modeled by tied overlapping shell elements, in order to simulate crack propagation.

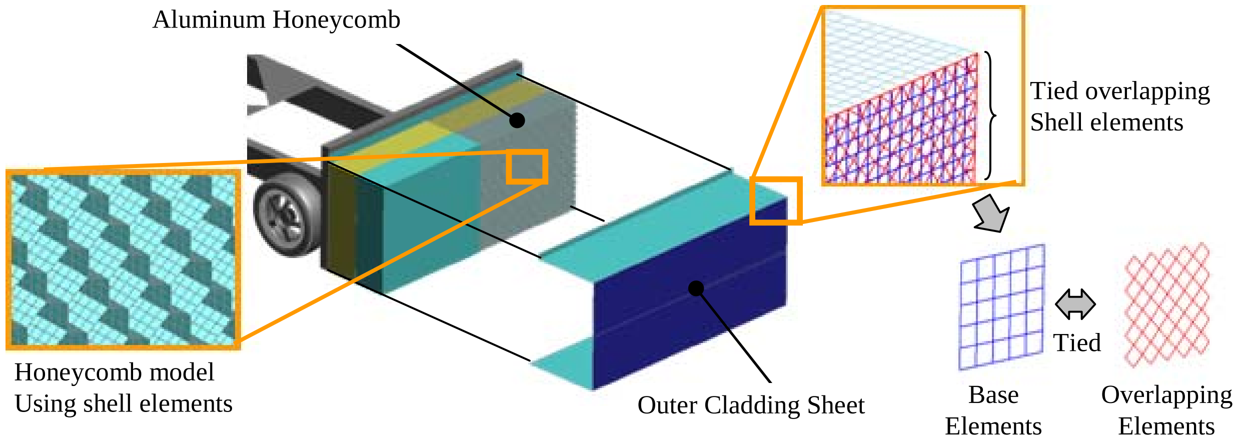


Figure 4. Aluminum honeycomb FE modeling method.

3.2 FE model of Car

In this study, prototype model of sedan type vehicle was used as Figure 5.

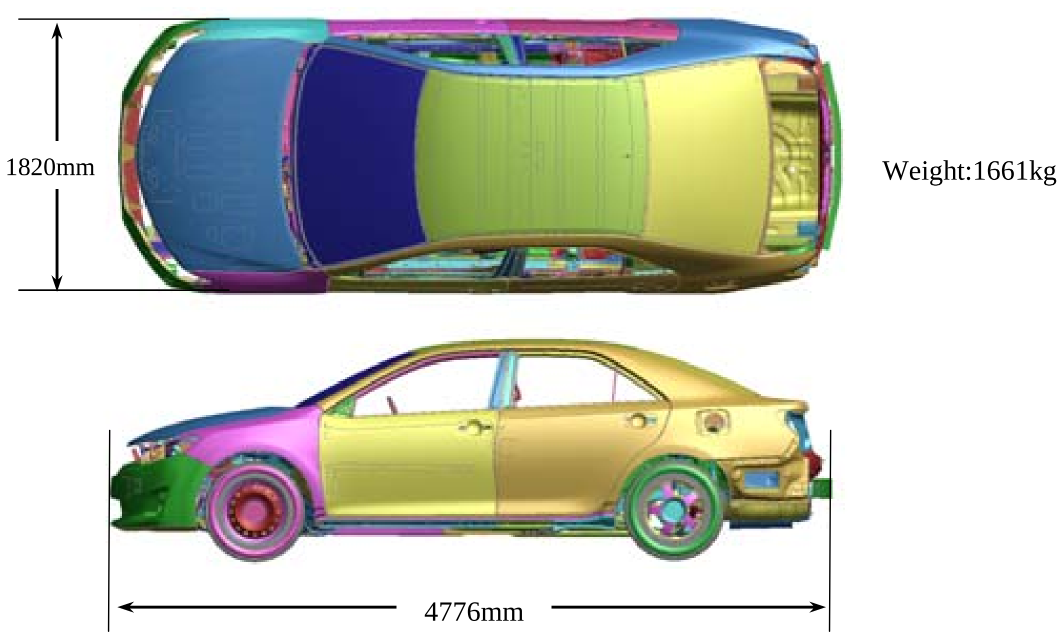


Figure 5. Car FE model.

4. Results

4.1 Impactor Test

The impactor model was developed to conduct impactor component testing. Impactor test conditions and impactor head shape is shown in Figure 6. Aluminum honeycomb was glued to the jig, and the impactor crashed into aluminum honeycomb at 33.12km/h.

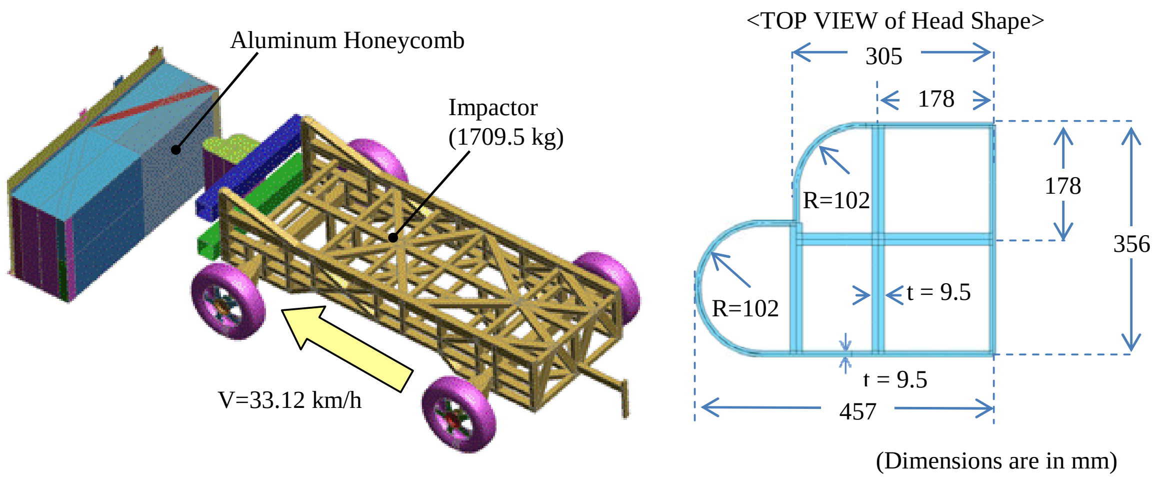
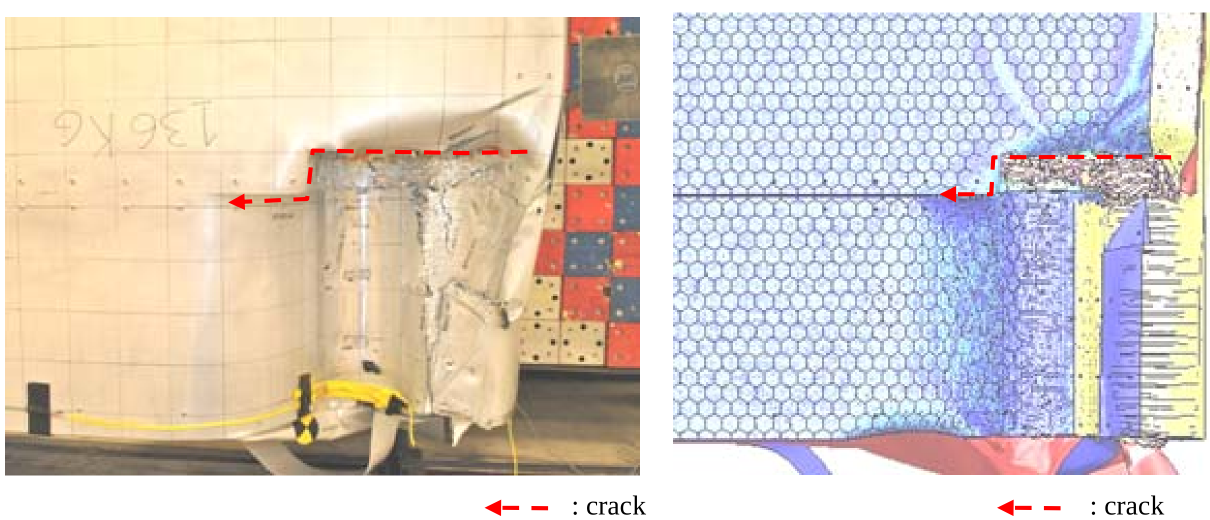


Figure 6. Impactor test model.

The crack propagation of the outer cladding sheet after test is presented in Figure 7. The fracture line on the outer cladding sheet from the test was reproduced in the FEM. Impactor acceleration-displacement curves are shown in Figure 8, and the acceleration data correlated to test.



(a) Impactor Test

(b) FEM

Figure 7. Comparison of crack propagation.

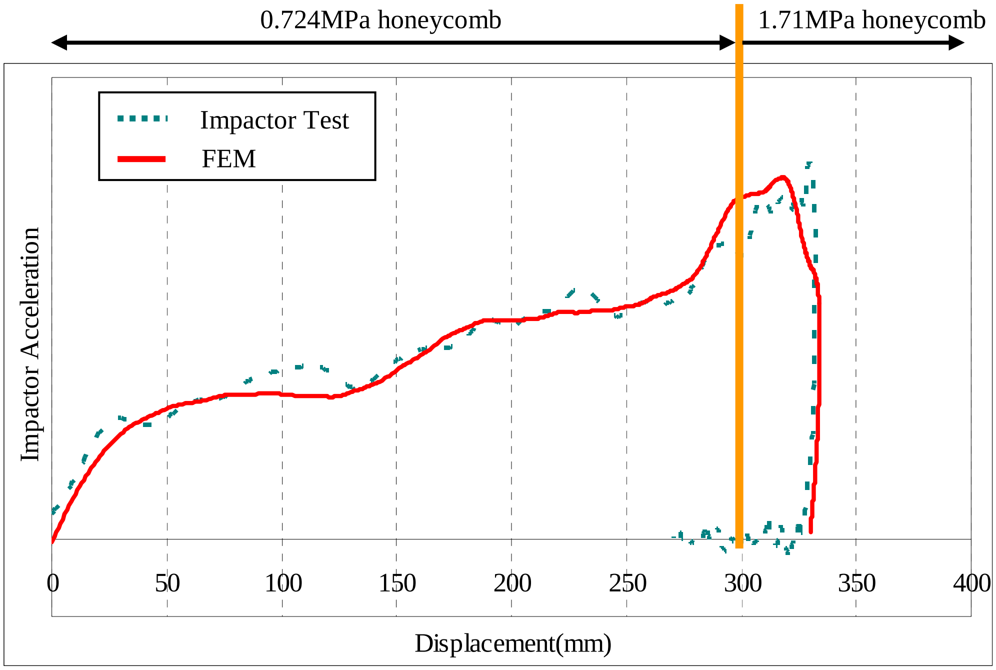


Figure 8. Comparison of impactor acceleration-displacement curves.

4.2 Full Car Test

Full car testing was performed refer to the SAE paper [3] as shown in Figure 1. The RMDB and car kinematics for both test and FEM calculation results are shown in Figure 9. Both car velocities in x and y direction are presented in Figure 10. The velocity was measured at driver side rocker, and FEM result was correlated to test result. Structure deformation is shown in Figure 11 using key measurement point, and FEM deformation result was correlated to the test result. Intrusion numbers of toe-pan and A-pillar are shown in Figure 12, which relatively ranked to the test result.

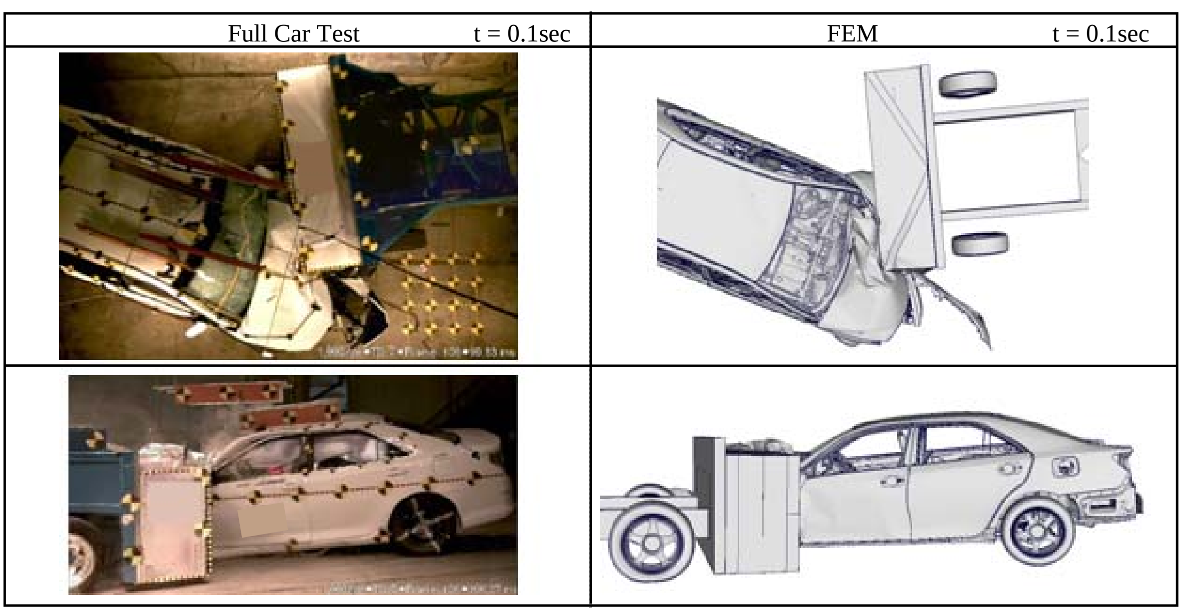


Figure 9. Comparison of the vehicle and barrier deformation.

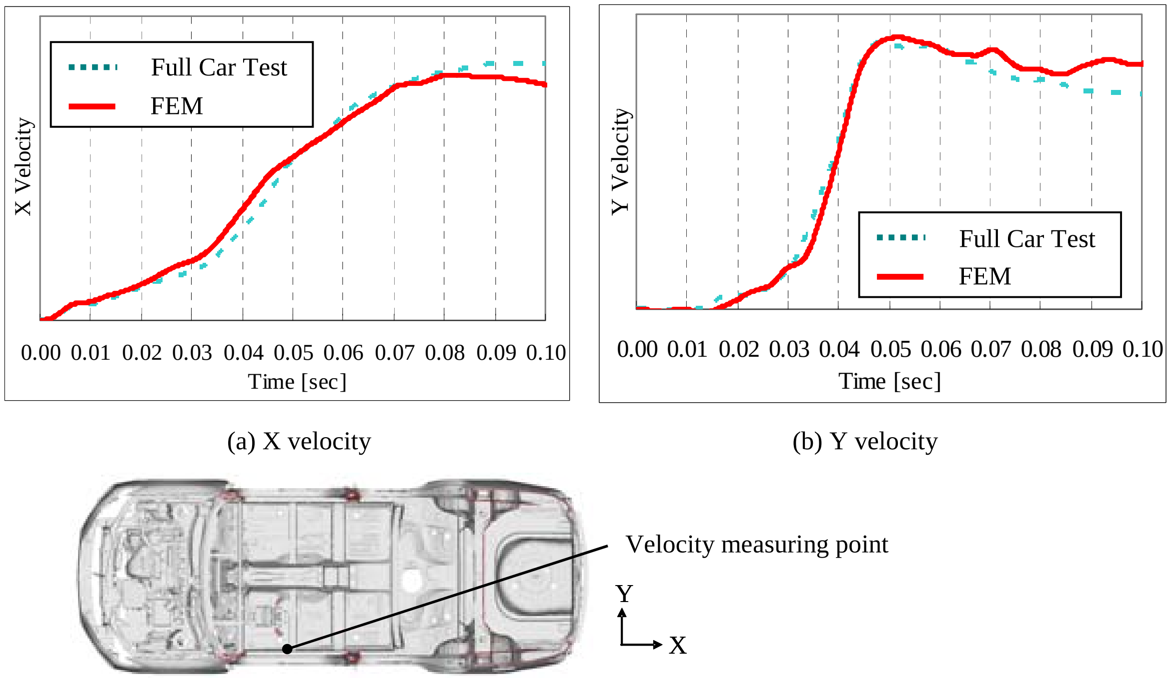


Figure 10. Comparison of vehicle velocity time history.

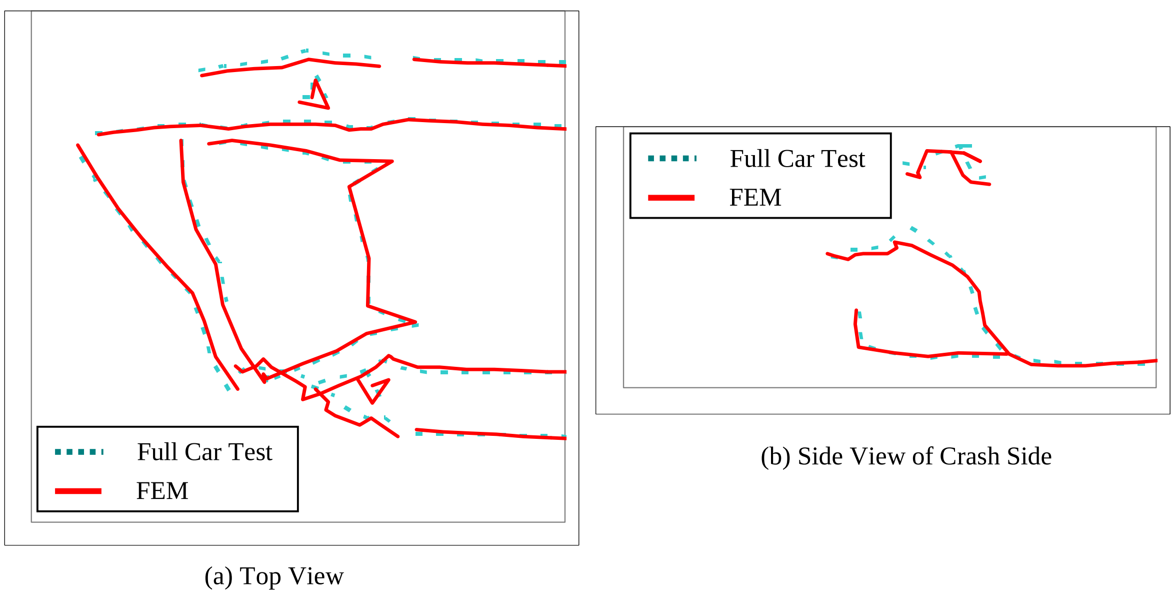
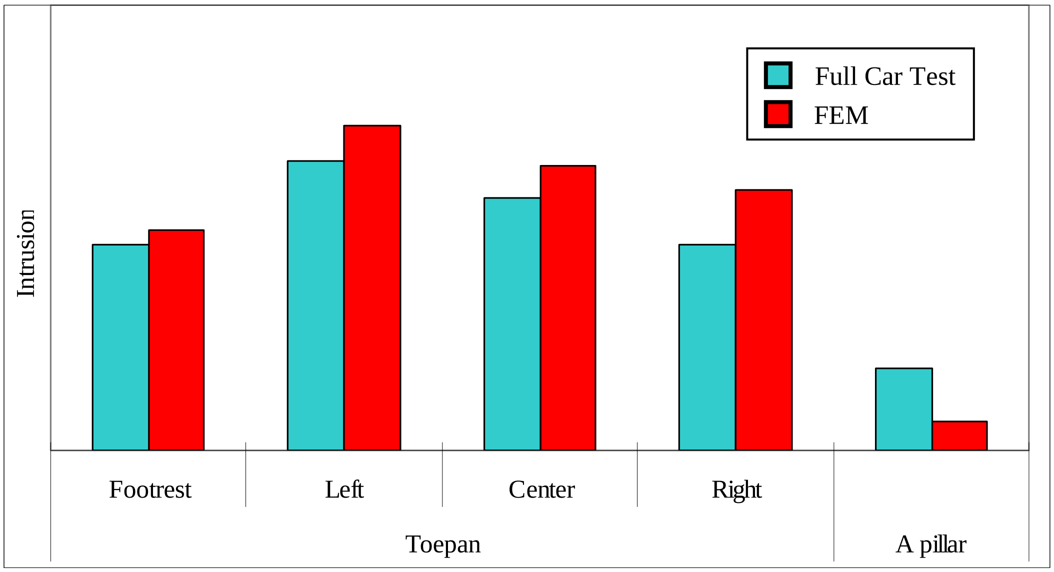


Figure 11. Comparison of structure deformation.



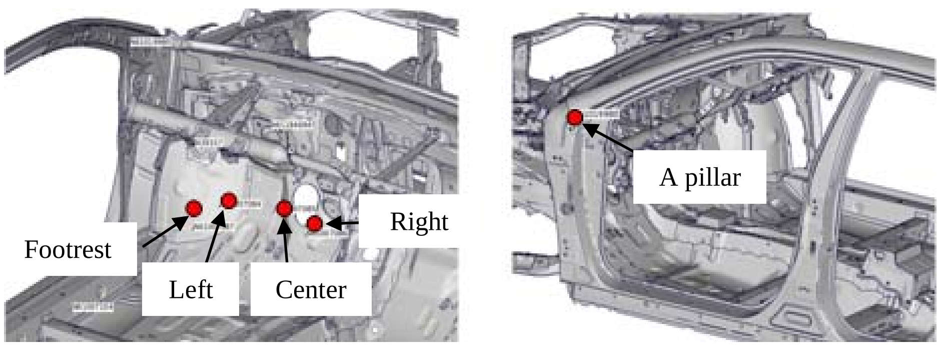
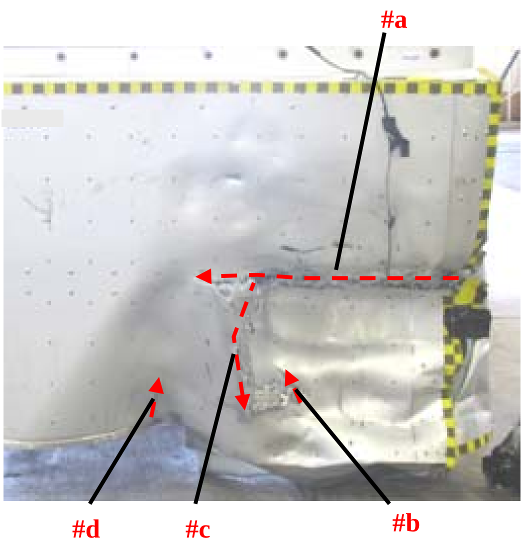
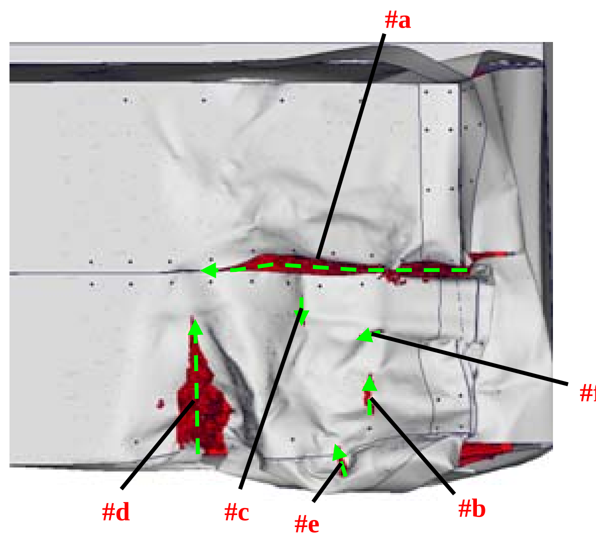


Figure 12. Comparison of body intrusion numbers.

The cracks observed on the outer cladding sheet are presented in Figure 13 for both car test and FEM result. In the FEM, cracks were observed at the sheet boundary (#a), the radiator support edge (#b), the bumper reinforcement edge (#c, #f), the wheel outer rim edge (#d), and at the suspension member edge (#e). Crack initiations, #a - #d, correlated to test, and the largest crack length, #a, also correlated to test, but #e and #f cracks weren’t observed in the test result. Although the length of #c and #d cracks were different from the test, the FEM largely reproduces the test results.



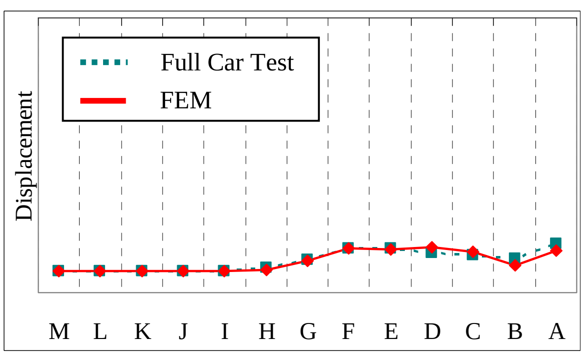
(a) Full Car Test



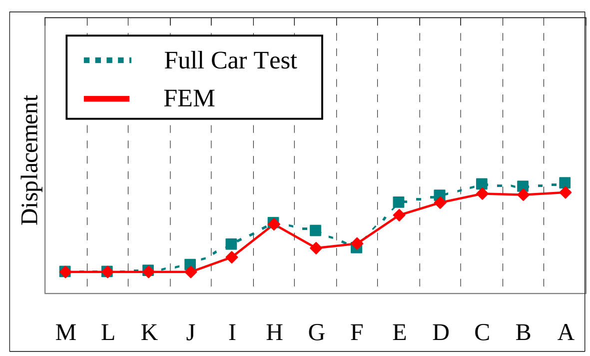
(b) FEM

Figure 13. Comparison of cracks on the outer cladding sheet.

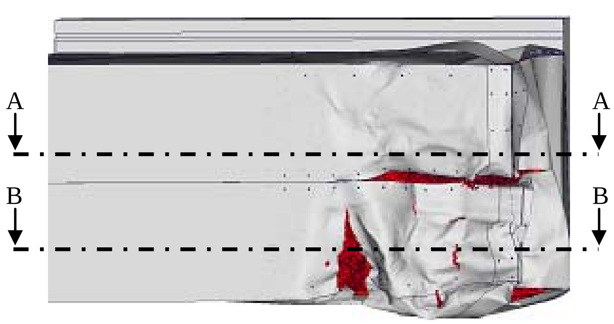
The deformation of the aluminum honeycomb is shown in Figure 14-(a) and (b). Location of the section and measuring line was presented in Figure 14-(c) and (d). Deformation at A-A section and B-B section, was close to the test deformation result.



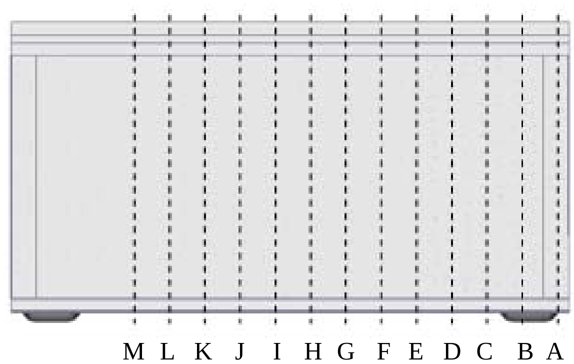
(a) A-A section



(b) B-B section



(c) Cross section position (Front view)



(d) Measuring line (Front view)

Figure 14. Comparison of aluminum honeycomb deformation.

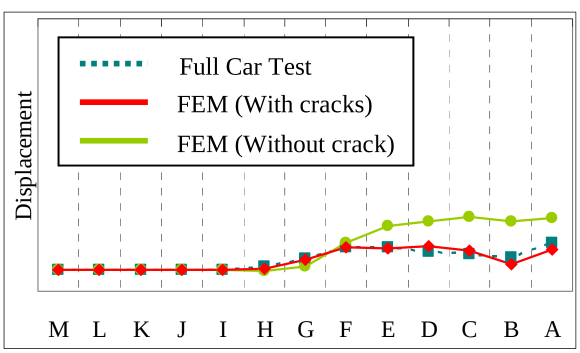
5. Discussion

In order to investigate the effects of the crack propagation, full car simulation with no cracking in the outer cladding sheet was performed. Comparison of outer cladding sheet with cracks phenomena and without crack phenomena was shown in Figure 15.

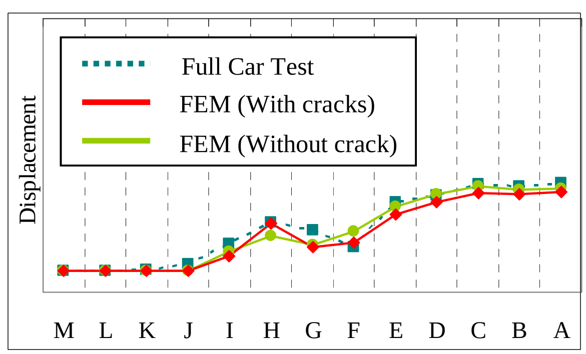
Aluminum honeycomb deformation was shown in Figure 16. The analysis indicated that deformation at A-A section differed depending on whether outer cladding sheet had cracks or not. Engine x velocity was also different, and it is presented in Figure 17 using time history of velocity. The aluminum honeycomb deformation at 0.03 second is shown in Figure 18. It was found that aluminum honeycomb, without crack propagation phenomena, deformed compressively due to pulling from outer cladding sheet, and led the honeycomb to generate higher loads and resulting in changes in engine velocity.

(a) With cracks (b) Without crack

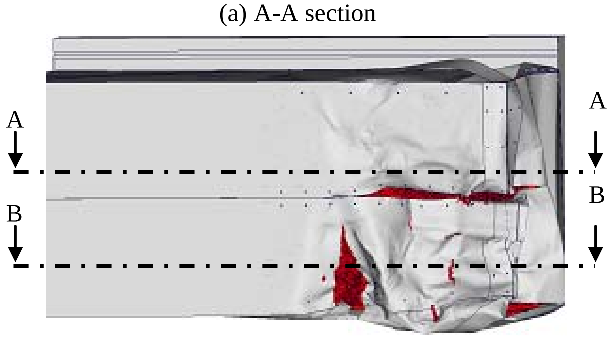
Figure 15. Comparison of cracks on the outer cladding sheet.



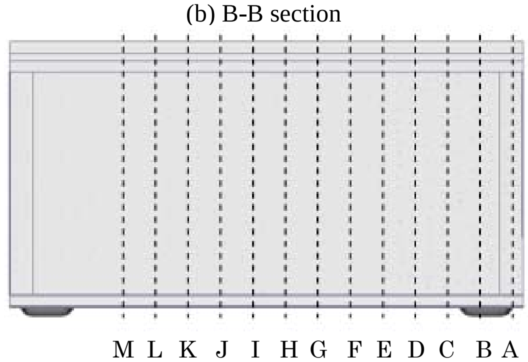
(a) A-A section



(b) B-B section



(c) Cross section position (Front view)



(d) Measuring line (Front view)

Figure 16. Section comparison of aluminum honeycomb deformation.

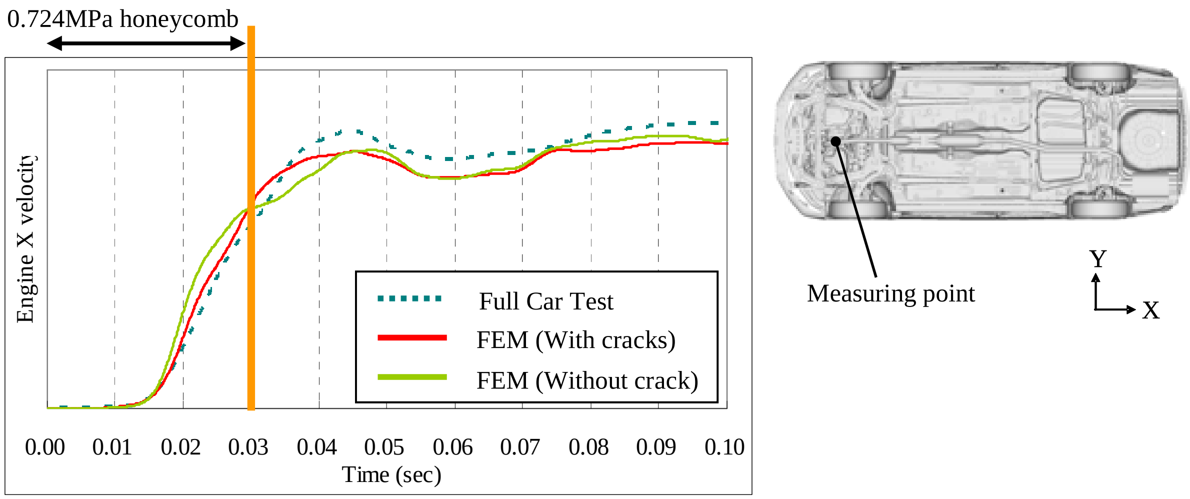
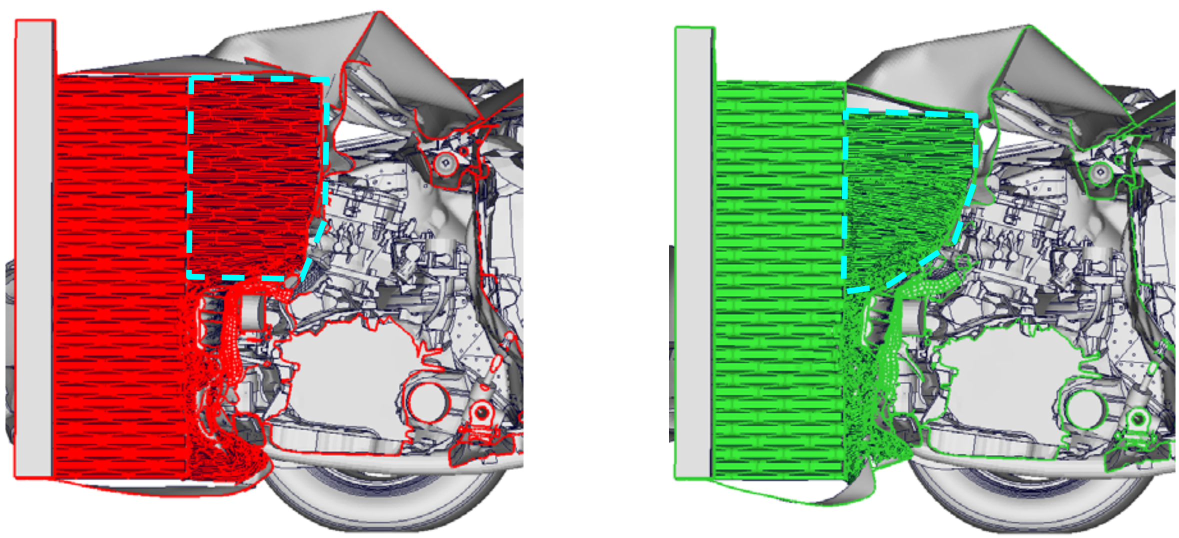


Figure 17. Time history of engine x velocity



(a) With cracks (b) Without crack

Figure 18. Comparison of aluminum honeycomb deformation at 0.03 sec.

6. Limitations and Suggestion for Future Work

Although RMDB FE model developed in this research closely reproduced the test result, the research itself was limited in terms of vehicle types and test conditions. Consequently, the validation results cannot confirm the validity of the RMDB FE model for various vehicle types and test conditions. Further research is needed for oblique crash analysis using this RMEB FE model.

7. Conclusion

(1) A RMDB FE model for oblique crash test was developed by Toyota Motor Corporation.
(2) The new RMDB FE model reproduced to the impactor test results and the full car test results.
(3) The deformation of the upper aluminum honeycomb differed based on whether the outer cladding sheet had cracks or not, and engine velocity was affected by that deformation.

References

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