EVALUATION OF MOVING PROGRESSIVE DEFORMABLE BARRIER TEST METHOD BY COMPARING CAR TO CAR CRASH TEST

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ABSTRACT

Honda has a long history of studying Car-to-Car frontal collisions as a part of our real world crash safety research. This research led to the original Advanced Compatibility Engineering (ACE) frame, first introduced at ESV 2003. ACE was developed for the purpose of improving compatibility performance and has been widely applied to Honda's mass production vehicles. Since Honda's original Car-to-Car testing, the Moving Progressive Deformable Barrier (MPDB) test has been examined as a possible test to represent the behavior of Car-to-Car frontal collisions. However, the research about the similarity of MPDB test to an actual Car-to-Car crash mode is quite limited. The objective of this study is to evaluate MPDB test method by comparing results from MPDB tests to actual Car-to-Car crash tests. These results are used to propose improvements in MPDB test condition for improving the ability of the MPDB to reproduce an actual Car-to-Car crash.

INTRODUCTION

Today, offset deformable barrier tests and flat rigid barrier tests are being used to evaluate crash safety in frontal collisions throughout Europe and in nations including the US and Japan. However, because the initial energy in these test methods is determined by the subject vehicle's own mass and speed, they do not provide adequate evaluation of safety in the event of a collision with a heavier vehicle.

In order to address this issue, Frontal Impact and Compatibility Assessment Research (FIMCAR) [1] has been advanced as a means of evaluating front-to-front compatibility. In addition, Allgemeiner Deutscher Automobil-Club e.V. (ADAC) has advanced research based on these studies, and Car-to-MPDB tests will be introduced to the Euro-NCAP. However, while studies have been conducted on the ability of these methods to reproduce Car-to-Car collisions, they only examined smaller vehicles[2]. Figures 1, 2 and 3 respectively show the test method currently being used by ADAC and the characteristics of Progressive Deformable Barriers (PDB).

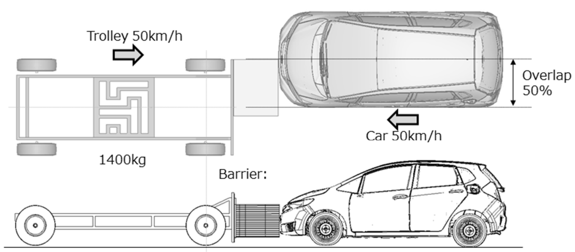

Figure 1. ADAC proposal test condition.

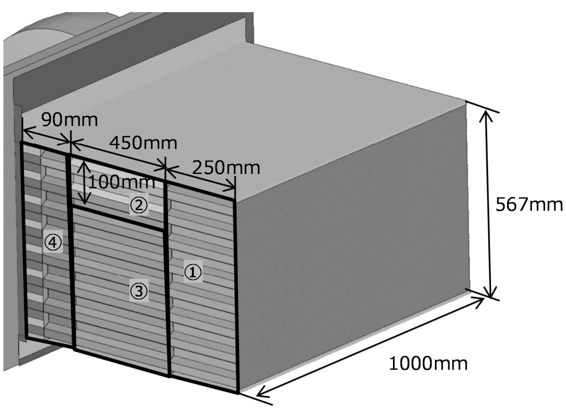

Figure 2. Dimension of PDB.

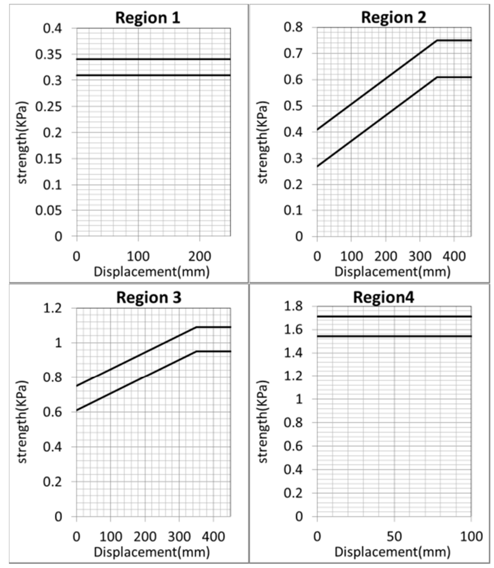

Figure 3. PDB characteristics.

Honda began conducting compatibility research in 1999. From this compatibility research, the company has developed an Advanced Compatibility Engineering (ACE) structure, the intention of which is to reduce aggressiveness and increase self-protection performance for small cars in Car-to-Car collisions. Honda has applied the ACE structure to several mass-production vehicles [3].

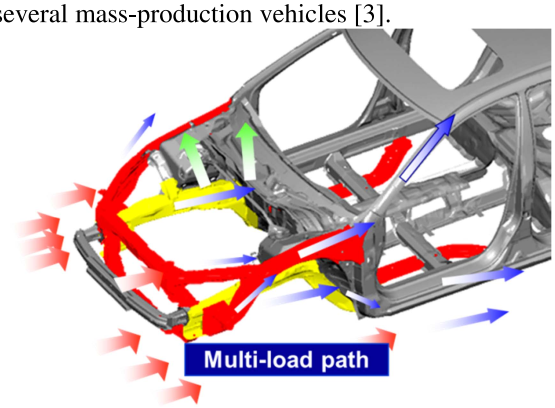

Figure 4. Advanced Compatibility Engineering Structure.

ADAC currently recommends a weight of 1400 kg for MPDB. Following Honda's own internal standard, Honda conducts Car-to-Car crush tests with mid-size sedans (approximately 1750 kg) for models the size of a small sedan and smaller.

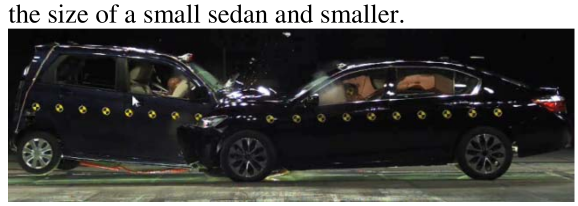

Figure 5. Car-to-Car crash test between Kei car and mid-size sedan.

According to the Crashworthiness Data System(CDS)[4], which compiles samples of accident data for USA, the use of 1750 kg as the weight of the partner vehicle makes it possible to cover 60% of AIS3+ injuries in Car-to-Car frontal collisions.

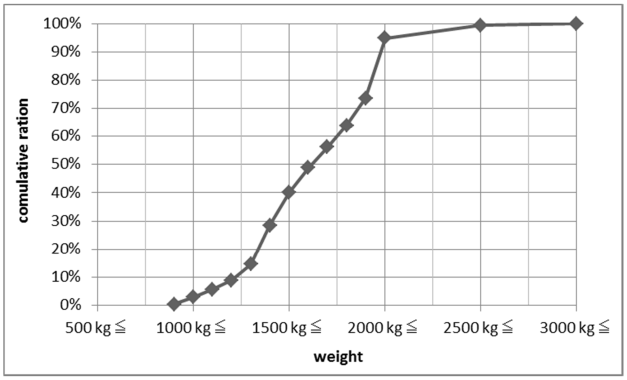

Figure 6. Weight of partner vehicle in Car-to-Car collisions resulting in AIS3+level injuries in the US (2000-2013).

Against the background described above, the research discussed in this paper focused on the realization of increased self-protection performance, and examined the ability of Car-to-MPDB tests with an MPDB of 1750 kg to reproduce Car-to-Car crashes using simulation.

COMPARISON WITH SIMULATAION AND ACTUAL TEST

The research under discussion employed LS-DYNA models in conducting simulation studies. Figures 7, 8, and Table 9 compare the results of an actual Car-to-MPDB test with the results of a simulation using a corresponding FEM model. The results demonstrated that the simulation was able to reproduce the vehicle’s deceleration characteristic and the deformation of the honeycomb, indicating no issues in relation to the accuracy of the simulation.

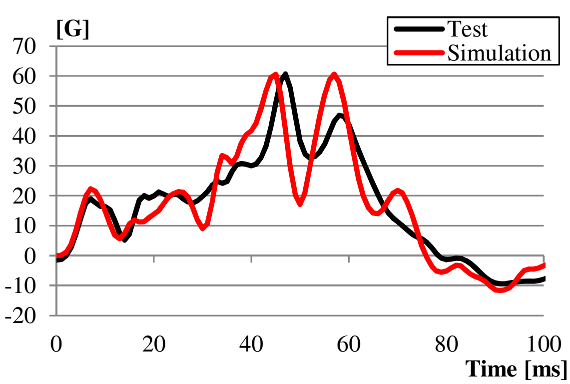

Figure 7. Vehicle body deceleration.

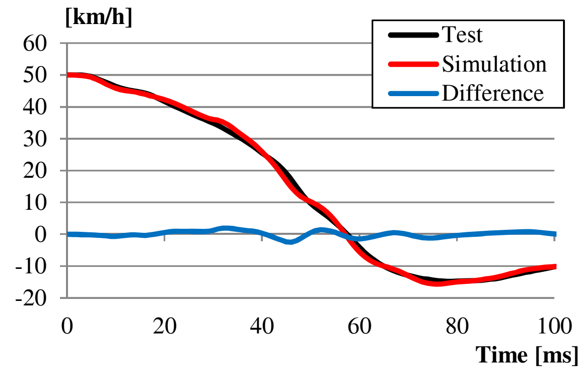

Figure 8. Vehicle body velocity.

Table 1.
Occupant Load Criterion (OLC) [5] comparison

	Test	Simulation
OLC	38.0	39.4

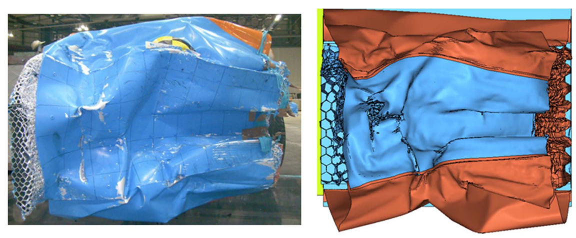

Figure 9. PDB deformation following test (Left: Actual vehicle test: Right: Simulation).

STUDY OF PDB GROUND CLEARNACE

The research commenced by studying the ground clearance of the lower surface of the honeycomb. The lower sections of cars are sometimes fitted with frames that act as load-distributing structures in a crash (Figure 10), and this also affects the partner vehicle in Car-to-Car crashes.

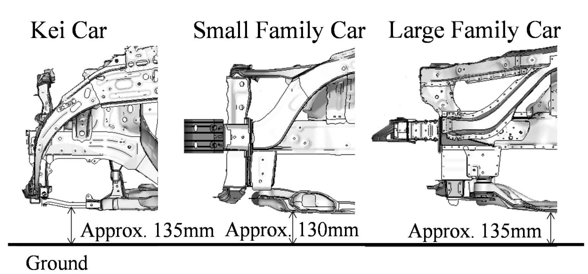

Figure 10. Frames on lower sections of cars and their ground clearance.

Figure 11 shows the results of varying the ground clearance of the PDB from 125 mm, to 190 mm, to 300 mm.

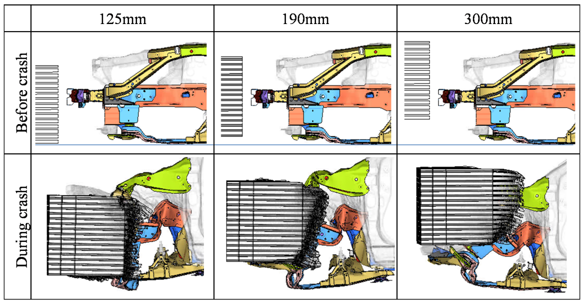

Figure 11. Ground clearance and lower frame deformation following crash.

When the ground clearance of the lower surface of the honeycomb is 190 mm and 300 mm, the lower frame passes under the honeycomb, and because of this the simulation is not able to reproduce the same situation as a Car-to-Car crash. In order to reproduce the action of lower frame, the ground clearance of lower surface of honeycomb was therefore set at 125 mm.

COMPARISON BETWEEN CAR-TO-CAR AND CAR-TO-MPDB

Next, Car-to-Car and Car-to-MPDB were compared using a small SUV. Because the weight of the small SUV for the test was 1850 kg, a trolley weighing 1750 kg was also used for the MPDB (Figure 12). The results are shown in Figures 13, 14, 15, and Table 2.

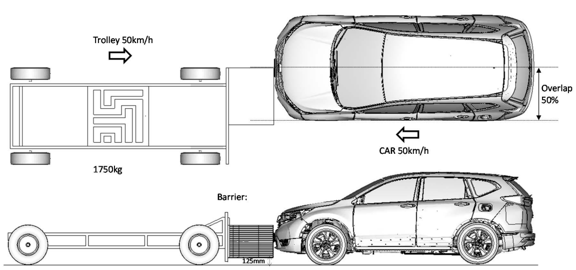

Figure 12. Car-to-MPDB conditions for comparison with Car-to-Car.

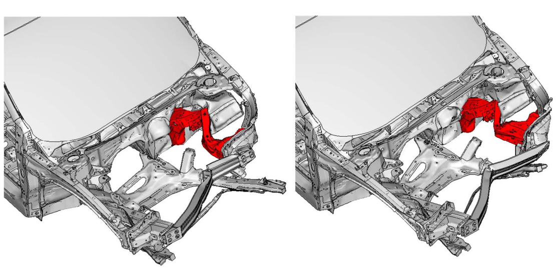

Figure 13. Body deformation (Left: Car-to-Car, Right: Car-to-MPDB).

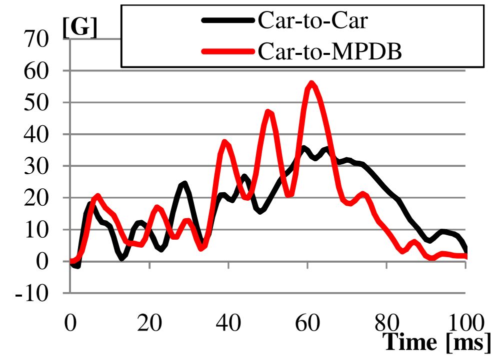

Figure 14. Vehicle body deceleration.

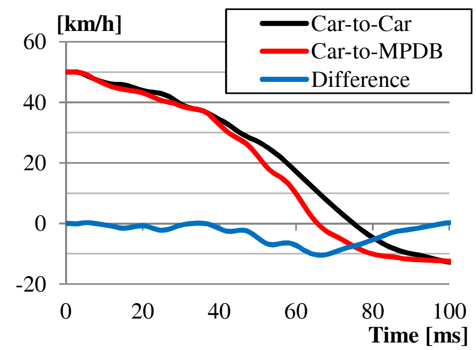

Figure 15. Vehicle body velocity.

Table 2. OLC comparison

	Car-to-Car	Car-to-MPDB
OLC	25.8	31.2

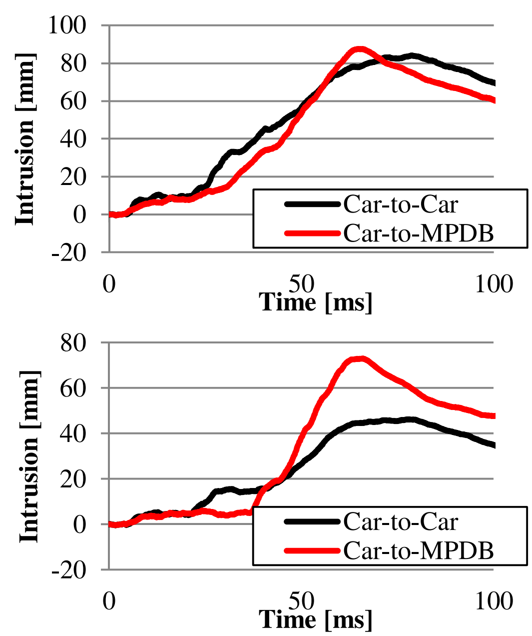

Figure 16. Time history of Intrusion at point of lower extremities (Above: Left toe board, Below: Right toe board).

Table 3.
Maximum intrusion close to lower extremities during crash

	Car-to-Car	Car-to-MPDB
Right toe board	46mm	73mm
Left toe board	84mm	88mm

While the extent of deformation differed, it was possible to reproduce the mode of the deformation of side frame (Figure 13). However, body deceleration were considerably higher during the latter phase of deceleration for Car-to-MPDB (Figures 14, 15, and Table 2), and the degree of intrusion also differed (Figure 16, Table 3).
As a result, there were differences also in the injury values. The figures below show waveforms for Head G, Chest deflection, and Tibia Index.

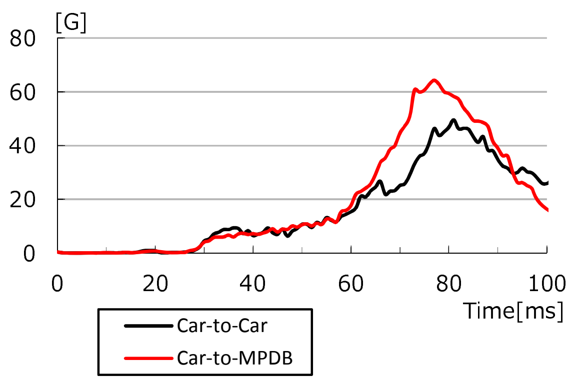

Figure 17. Head G.

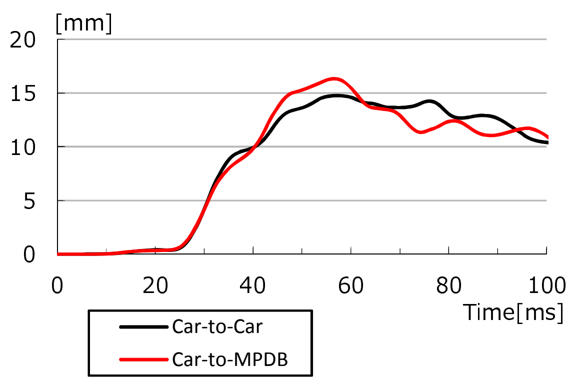

Figure 18. Chest deflection.

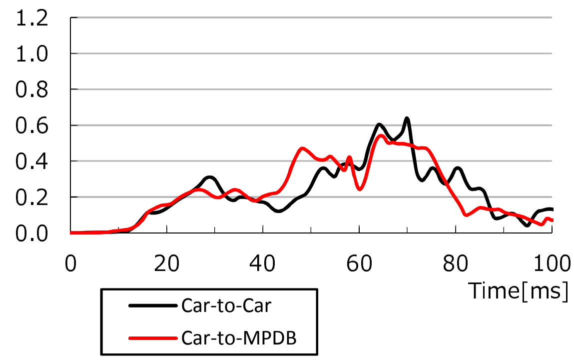

Figure 19. Left Tibia Index.

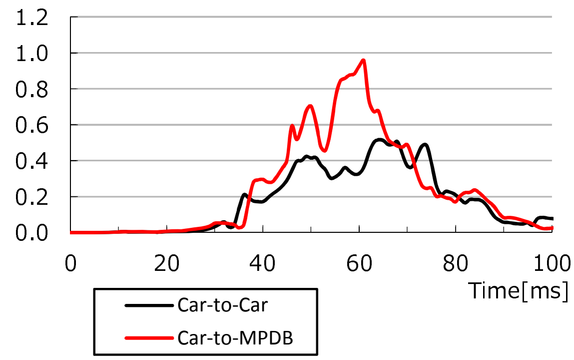

Figure 20. Right Tibia Index.

Chest deflection was basically reproduced, but in the case of Head G, which is strongly influenced by the deceleration characteristic, and the right Tibia Index, which is strongly influenced by intrusion at the toe board, it was not possible for Car-to-MPDB crashes to reproduce the results of Car-to-Car crashes, with the former producing results approximately twice as high as the latter. However, in the case of the left Tibia Index, for which vehicle intrusion was accurately reproduced, the injury values were also reproduced, indicating that it is possible to reproduce the Tibia Index by reproducing intrusion more accurately.

CAUSES OF DIFFERENCES IN VEHICLE BODY CHARACTERISTICS

Figure 21 shows the movement of the engine in Car-to-Car and Car-to-MPDB crashes. In the Car-to-Car crash, the side frame alone pushes part of the engine through the bumper beam. Since the vehicle body's main body structure members are located inboard of the outermost body surface, the amount of overlap of the engine component in Car-to-Car crash is smaller than that in the Car-to-MPDB crash mode. Therefore, the different behavior of the engine leads to the different toe board intrusion.

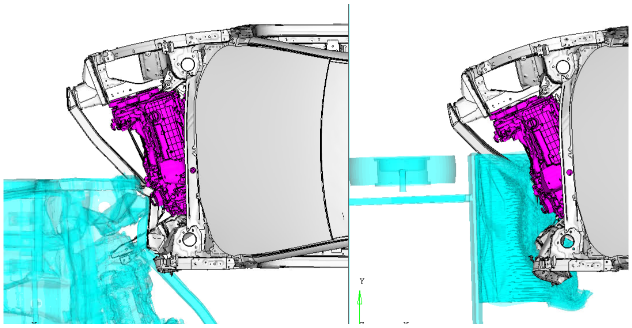

Figure 21. Movement of engine during crash (Left: Car-to-Car, Right: Car-to-MPDB).

MODIFIED PDB SHAPE

Based on the results discussed in the previous section, a study was conducted in order to determine whether changing the shape of the PDB would make it possible to better reproduce Car-to-Car crashes. The properties of front end structure are considered in side impact working group [6], [7] showing that the body stiffness in the center of the vehicle is less than the outer edge of the vehicle based on the actual vehicle investigation (Figure 22). However, the stiffness of the side crash MDB does not replicate this realistic stiffness distribution across the front of the barrier. As shown in Figure 23, the comparison between the engine room structure and PDB shape indicates that the stiffness in front of the engine is different.

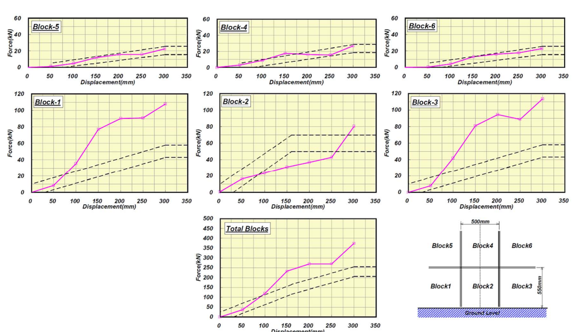

Figure 22. Vehicle front-end stiffness (weighted average based on 1998 car models)[6].

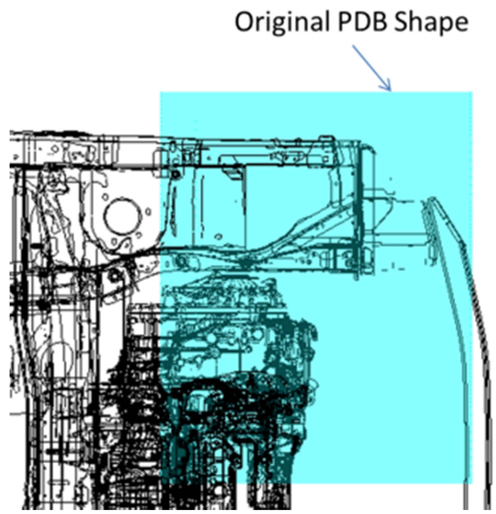

Figure 23. Comparison between engine room and PDB shape.

Figure 24 shows the proposed shape of PDB for reproducing such an issue. The concept is that the PDB volume is decreased with the actual part existence. In addition, to keep the reaction force of the modified structure same as that of the original one, a stiffer honeycomb material was used, as indicated in Figure 25.

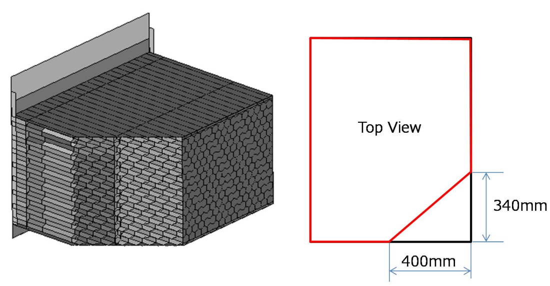

Figure 24. Dimension of modified PDB (Black: Base, Red: Modified shape).

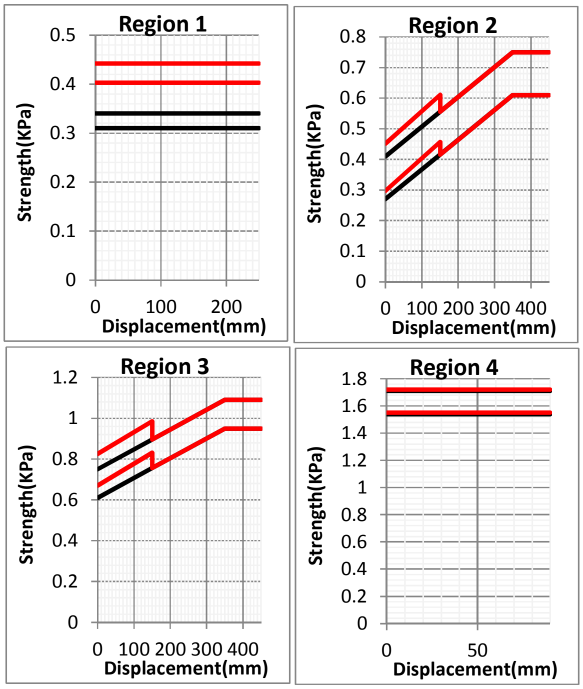

Figure 25. Modified PDB characteristics.
(Black: Original, Red: Modified shape).

Figures 26, 27, and Tables 4, 5 show a comparison of the results of a Car-to-MPDB crash using a model of the modified PDB shape and a Car-to-Car crash. While results for the Car-to-MPDB crash using the new shape were closer to the Car-to-Car results in terms of the vehicle body deceleration characteristic and deformation close to the left tibia, the divergence in the results for deformation close to the right tibia were greater than in the previous results. This was due to the fact that the movement of the engine in the Car-to-Car crash had not been fully reproduced.

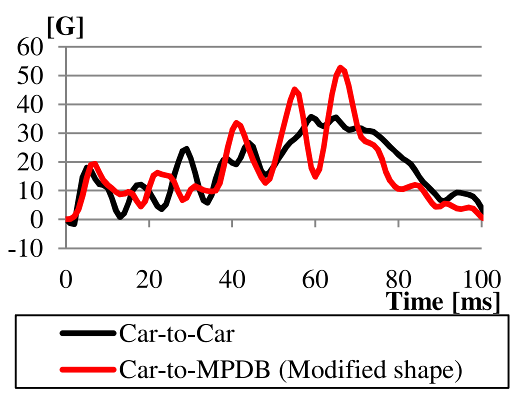

Figure 26. Vehicle body deceleration.

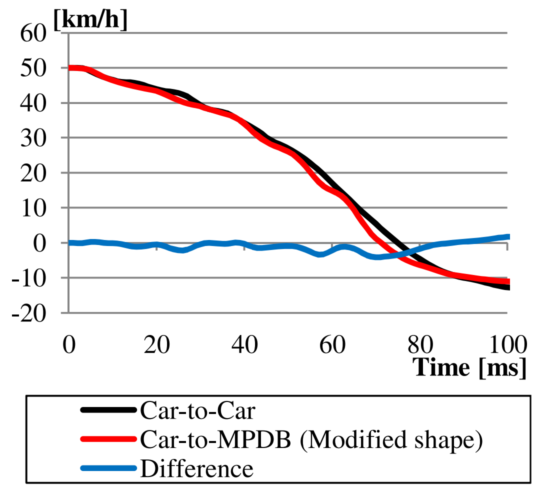

Figure 27. Vehicle body velocity.

Table 4.
OLC comparison

	Car-to-Car	Car-to-MPDB (Modified shape)
OLC	25.8	28.2

Table 5.
Maximum intrusion close to lower extremities during crash

	Car-to-Car	Car-to-MPDB (Modified shape)
Right toe board	46mm	80mm
Left toe board	84mm	75mm

EFFECT OF OFFSET DISTANCE

In general, it is known that the width of the structural components is smaller than the vehicle width, which is about 100mm and 5% of the vehicle width. The stiffness of PDB is uniform in the width direction, which might be considered as the main structural components, leading to the different loading condition between Car-to-Car and Car-to-MPDB crash mode, even if the offset overlap ratio is 50%. In this study, the offset overlap ratio is changed to 45% in order to minimize such difference as shown in Figure 28. The simulated deceleration and velocity time history shows the good agreement with Car-to-Car crash mode as shown in Figure 29 and 30, Table 6.

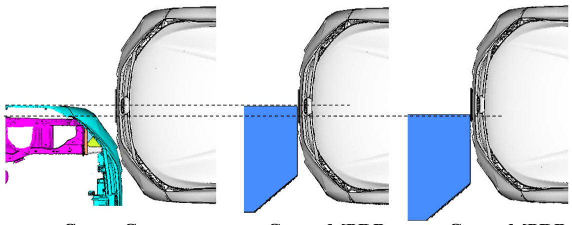

Figure 28. Layout comparison in Car-to-Car and Car-to-MPDB.

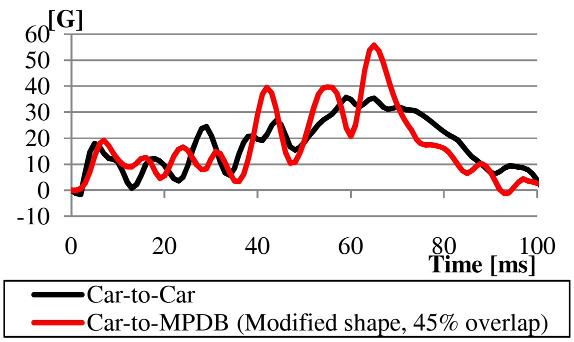

Figure 29. Vehicle body deceleration.

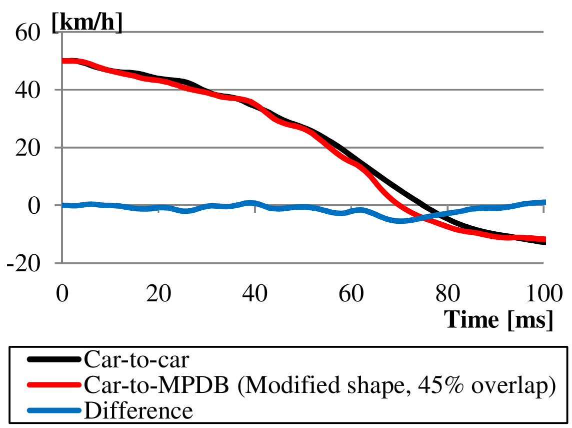

Figure 30. Vehicle body velocity.

Table 6.
OLC comparison

	Car-to-Car	Car-to-MPDB (Modified shape, 45% overlap)
OLC	25.8	28.5

Table 7.
Maximum intrusion close to lower extremities during crash

	Car-to-Car	Car-to-MPDB (Modified shape, 45% overlap
Right toe board	46mm	69mm
Left toe board	84mm	75mm

The figures below show waveforms for Head G, Chest deflection, and Tibia Index

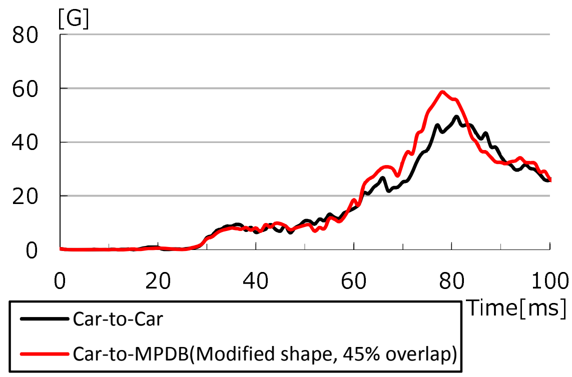

Figure 31. Head G.

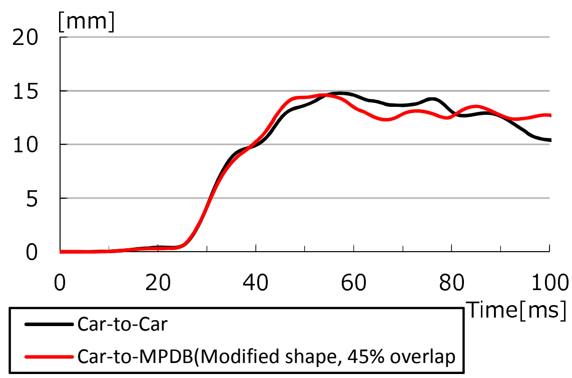

Figure 32. Chest deflection.

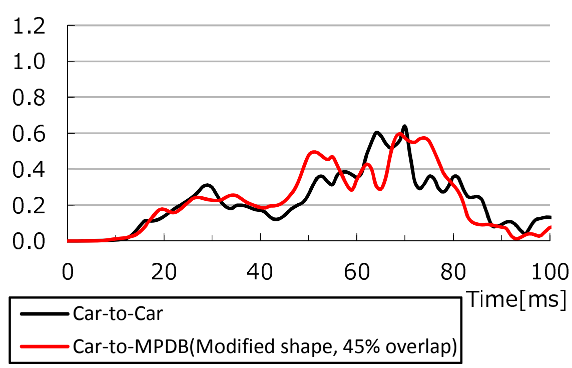

Figure 33. Left Tibia Index.

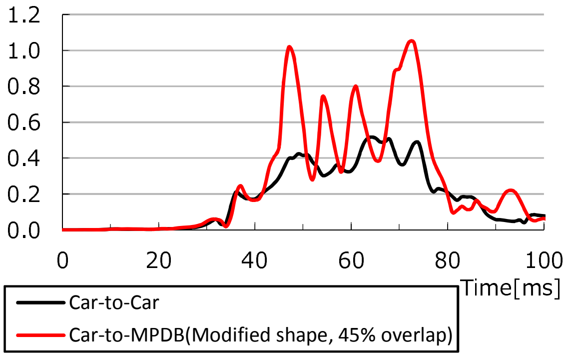

Figure 34. Right Tibia Index.

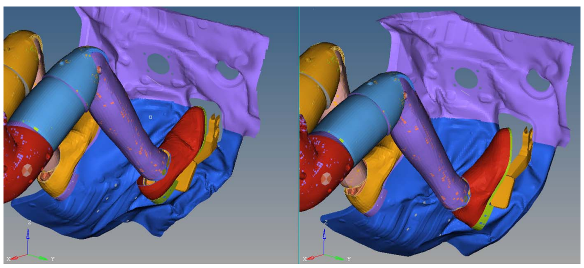

Figure 35. Movement of right foot during crash. (Left: Car-to-Car, Right: Car-to-MPDB)

Through improving the reproducibility of Car-to-Car, not only Chest deflection but also Head G were reproduced. However, right Tibia Index was not improved the reproducibility. This is because the foot movement was different from Car-to-Car and Car-to-MPDB due to local deformation of toe board close to right ankle.

MINI CAR VS NEW MPDB AND MINI CAR VS SMALL SUV

The study next focused on whether it would be possible to simulate a Car-to-Car crush between a mini car (test weight: 1350 kg) and a small SUV using the modified MPDB (changed shape and overlap). Figures 36 and 37, Tables 8 and 9 show the results.

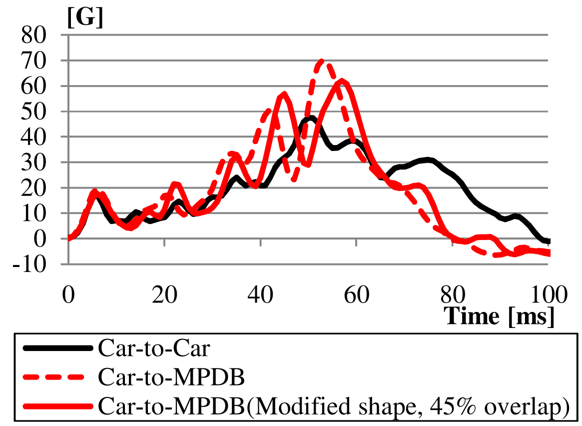

Figure 36. Vehicle body deceleration.

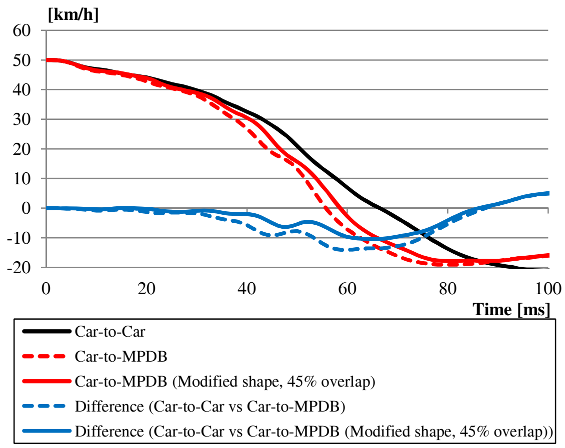

Figure 37. Vehicle body velocity.

Table 8.
OLC Comparison

	Car-to-Car	Car-to-MPDB	Car-to-MPDB (Modified shape, 45% overlap)
OLC	34.6	41.8	39.5

Table 9.
Maximum intrusion close to lower extremities during crash

	Car-to-Car	Car-to-MPDB	Car-to-MPDB (Modified shape, 45% overlap)
Right toe board	132mm	173mm	182mm
Left toe board	88mm	101mm	114mm

In the case of mini car also, the body deceleration characteristic was closer to the results for Car-to-Car crash rather than original MPDB, but results deviated for the amount of body deformation at the toe board. The deceleration time history shows a good agreement although the toe board instrusion shows a large difference.

DISCUSSION

The Euro-NCAP, which commenced evaluations in 1997, has dramatically increased automotive crash safety. In order to further improve crash safety, it is necessary to consider performance in crashes between the subject vehicle and heavier vehicles. The introduction of Car-to-MPDB test is considered to represent an extremely effective means of achieving this goal. Based on actual accident data, it can be considered desirable to set 1750 kg as the weight of the MPDB in these tests. However, if the deformation around lower extremities area is greater in Car-to-MPDB crashes than in Car-to-Car crashes, the loads on the front side members will be greater in order to reduce this, and there is a possibility that the potential of the large vehicle to cause damage will ultimately be increased. The ability to reproduce Car-to-Car crashes is therefore important [8].
It is believed that the current PDB specification ability to match the deceleration and toe board intrusion seen in the Car-to-Car crash is limited. This is because the current PDB shape cannot reproduce the engine room structure. Modifying the PDB shape did improve the reproducibility in the case of small SUV Car-to-Car crash. However, in the case of mini passenger vehicle Car-to-Car crash, both the deceleration time history, and toe board intrusion did not improve enough. It is to be considered that the mini passenger vehicle has a smaller engine room size with small clearance in the rear of the engine component, leading to a different engine movement against the toe board. It is observed that the engine rotation and movement is different in the crash event even though the initial rotation and movement of the engine component is similar in Car-to-Car and Car-to-MPDB crash modes. This is more prominent in the mini passenger Car-to-Car crashes.

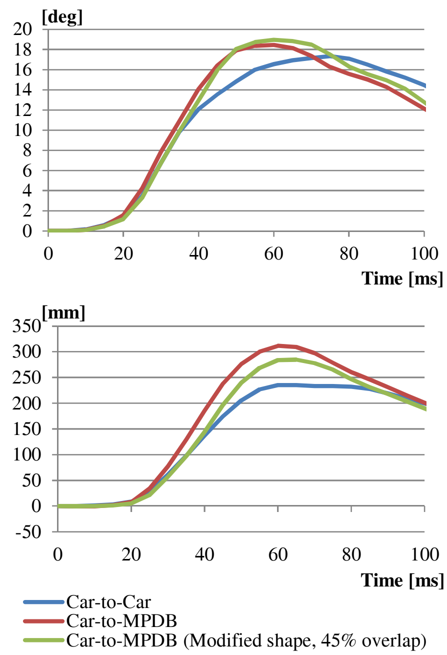

Figure 38. Engine component displacements (Above: Rotation, Below: Toe board intrusion againt passenger vehicles).

In addition, it is necessary to develop a PDB shape based on the engine room layout. In the next step, the behavior of the engine component will be analyzed, leading to a modified PDB specification while the engine room component is surveyed.

CONCLUSIONS

The results of studies using CAE showed that a ground clearance of 125 mm for an MPDB would be effective for crash reproduction.
A comparison of Car-to-Car and Car-to-MPDB crashes for the case of a small SUV vs. a small SUV using current PDB specifications showed that the deceleration characteristic was higher, and intrusion around the right tibia area was greater for the Car-to-MPDB.
Modifying the PDB shape to reflect the engine housing layout of an actual vehicle produced results for the body deceleration characteristic closer to those of a Car-to-Car.
The results obtained after these findings were reflected in a mini car-to-MPDB. The results showed, similarly, that the body deceleration characteristic was more accurately reproduced than it had been by the pre-modification PDB specifications, but the deformation difference close to lower extremities between Car-to-Car and Car-to-MPDB was larger than that in the case of small SUV.

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