A STUDY OF COMPATIBILITY TEST PROCEDURE IN FRONTAL IMPACT

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ABSTRACT

The purpose of this study is to examine compatibility test procedures proposed in the IHRA Vehicle Compatibility Working Group. Various crash tests were conducted with different vehicle weights and stiffness in our previous study, and each of the compatibility problems, namely mass; stiffness and geometric incompatibility were identified in these tests. In order to improve the compatibility, it is necessary to evaluate and control relevant vehicle characteristics of compatibility in test procedures.

According to the IHRA study, relevant aspects for compatibility in frontal impact are

- Good structural interaction
- Frontal stiffness matching
- Maintaining passenger compartment integrity
- Control the deceleration time histories of impacting cars

Possible candidate test procedures to evaluate four items given above are as follows:

1) A full width Load Cell Barrier test in which the load cell data was analyzed to evaluate structural interaction of vehicles, and some geometric indices such as Average Height Of Force, interaction area, and stiffness indices were measured. It was found from the analysis that several candidate metrics could be identified given their high correlation with laboratory vehicle-to-vehicle crash tests.

2) An MDB-to-vehicle test, which allows the mass ratio to be taken directly into account. Potentially it can generate a realistic delta V and vehicle acceleration pulse. It has been recognized that the MDB could be used as a representative of an actual vehicle, and it provides more flexibility in compatibility test procedures. MDB-to-vehicle tests were conducted to confirm the reproducibility of vehicle-to-vehicle tests; the test results and analysis are reported in this paper.

INTRODUCTION

Crash compatibility can be defined as the ability of a vehicle to help protect not only its own occupants, but other users as well. Compatibility in vehicle-to-vehicle crashes has become an issue in countries with various vehicle compositions; thus compatibility is strongly affected by fleet composition. The National Highway Traffic Safety Administration (NHTSA) reported the aggressivity issue of sport utility vehicles (SUV) and light trucks and vans (LTV) in the U.S. fleet [(1)]. In Japan, the sales volume of small and medium sedans has been decreasing over the past decades, and the sales of mini-cars, station wagons and minivans have been increasing. As the range of the vehicle composition has been spread widely in Japan, the concern with crash compatibility has been growing for the last several years.

After the International Harmonized Research Activity (IHRA) was set up, a number of studies have been made on compatibility between vehicles in the IHRA Vehicle Compatibility Working Group [(2)]. Referring to the IHRA work, various crash tests were performed with different vehicle weights and stiffness in our study, and each of the compatibility problems, namely mass; stiffness and geometric incompatibility were identified in these tests.

A major focus of compatibility research is a development of a laboratory test procedure to evaluate compatibility. Within the IHRA Compatibility WG, a number of possible candidate test procedures have been proposed for a frontal impact test. We have studied each of the proposed test procedures, and the present development activity is being focused on both a full width barrier test with load cells and an MDB test. In order to improve compatibility, it is necessary to evaluate and control relevant vehicle characteristics of compatibility in test procedures. According to the IHRA study, relevant aspects for compatibility in frontal impact are

- Good structural interaction
- Frontal stiffness matching
- Maintaining passenger compartment integrity
- Control the deceleration time histories of impacting cars

The work described in this paper provides a comparative analysis of the vehicle-to-vehicle test and vehicle-to-fixed/moving barrier test. The full width barrier test with load cells is mainly used to evaluate the aggressivity and the MDB test is intended to evaluate the self-protection. The barrier load cell data obtained from full width rigid barrier is analyzed to evaluate the aggressivity of a SUV/LTV, and the MDB-to-Car impact was compared to the SUV-to-Car impact.

SUV/LTV-TO-CAR CRASH TESTS

Test configuration

Figure 1a,b and Table 1 show the selected vehicles and their associated weight used in SUV/LTV-to-Car impacts. The target vehicle was a compact four-door sedan representing a small passenger car in the US fleet. SUV and LTV with different mass and geometry were selected for striking vehicles in SUV/LTV-to-Car impacts. SUV/LTV-to-Car crash tests have been performed with these cars impacted at 50 km/h each. The offset ratio for this test was 50% width of the compact sedan. Although a Hybrid Ⅲ 50^{th} percentile male dummy for the driver and a Hybrid Ⅲ 5^{th} percentile female dummy for the passenger was used in these SUV/LTV-to-Car impacts, however we limit the discussion to the structural behavior of these vehicles.

Figure 1a. SUV-to-Car impact.

Figure 1b. LTV-to-Car impact.

Table 1
Selected vehicles and test weight

Vehicle type	Vehicle test weight	Mass ratio
Compact Sedan	1310 kg	1.0
SUV	2205 kg	1.68
LTV	2680 kg	2.04

Figure 2a,b and Table 2 show the geometrical alignment of the two bullet vehicles compared to the target vehicle. Regarding the overlap of their front longitudinal member, there is no clear difference between the SUV-to-Car and LTV-to-Car, however the SUV has an engine sub-frame as an extra load path of the impact. In terms of structural interaction, the sub-frame could reduce the structural mismatch between the SUV and the compact sedan.

Figure 2a. SUV-to-Car.

Figure 2b. LTV-to-Car.

Table 2
Dimension of vehicle front-end structures

	Car	SUV	LTV
Longitudinal Top Height (mm)	510	550	590
Longitudinal Bottom Height (mm)	412	460	479
Sub-Frame Height (mm)	181	312	
Longitudinal Overlap (mm)		50	31

Crash test results

The deformation mode of the target vehicle is shown in figure 3a,b In the SUV-to-Car impact, the main element in the front structure of both vehicles absorbed kinetic energy and the passenger compartment integrity of the compact sedan was maintained. No over-riding phenomenon was seen in the SUV-to-Car impact. There was good structural interaction between the front longitudinal member of the passenger car and the sub-frame of the SUV.

However, in the LTV-to-Car impact the lack of the sub-frame of the LTV caused the structural mismatch between the two vehicles, thus it was a disadvantage for the vehicle aggressivity. Overriding phenomenon was seen in the LTV-to-Car impact. This overriding was caused by structural mismatch between the two vehicles. The LTV caused significantly more intrusion in the passenger compartment of the target vehicle compared to those caused by the SUV-to-Car impact. It was clear in the LTV-to-Car impact that there was little structural interaction due to geometrical difference that caused the LTV to override the target vehicle.

Figure 3a. Deformation of the target vehicle in the SUV-to-Car impact.

Figure 3b. Deformation of the target vehicle in the LTV-to-Car impact.

FULL WIDTH BARRIER LOAD CELL DATA ANALYSIS

Geometrical Compatibility

The LTV-to-car test result revealed that a poor structural interaction between two vehicles led to overriding. The difference in height between the vehicle front-end structures of the passenger car and the LTV is a good example to illustrate the geometric incompatibility. The geometric incompatibility must be examined in more detail.

Basically, the crash incompatibility is characterized by three vehicle factors:
(1) Mass Incompatibility
(2) Stiffness Incompatibility
(3) Geometric Incompatibility
Several studies have been made on a measurement of stiffness and geometric compatibility [(3), (4)]. NHTSA used a full width barrier test data with 36 load cells to evaluate stiffness and geometric compatibility [(5), (6)]. The full width rigid barrier test has been conducted in New Car Assessment Program (NCAP) in the US.

In this study, the load cell data of the NCAP test (36 Load Cells Barrier) and that of our in-house test (180 Load Cells Barrier) was used to assess the geometric and stiffness compatibility. The barrier load cell wall configurations are displayed in Figure 4a,b.

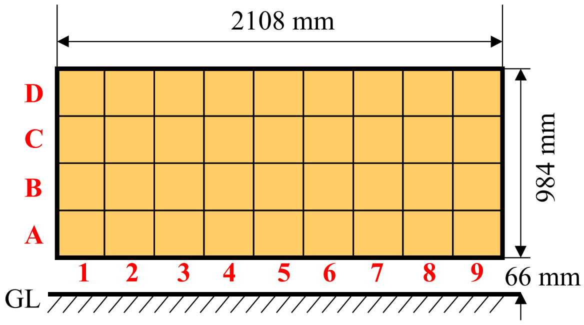


Figure 4a. 36 Load Cells Barrier configuration.

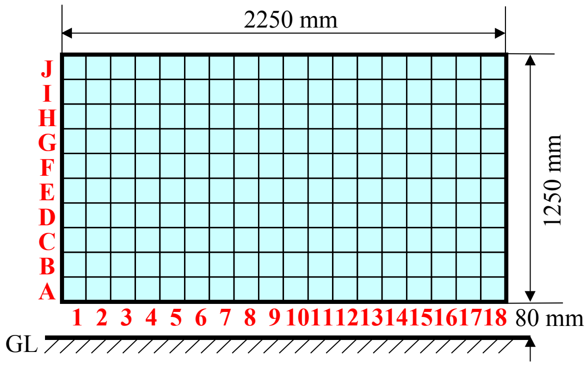


Figure 4b. 180 Load Cells Barrier configuration.

In order to assess the structural interaction, Average Height Of Force (AHOF) derived from the barrier load cell data was analyzed. The vehicle deflection was obtained by double integration of the acceleration derived from the accelerometer placed on the center of the vehicle. The barrier load cell data and the acceleration data were filtered with CFC 60 according to SAE J211 standard.

The Height Of Force (HOF) and the Average Height Of Force (AHOF) used in this study are computed as follows.

$$HOF(d) = \frac{\sum_{1}^{cell} Fi \times Hi}{\sum_{1}^{cell} \mathrm{F}i}$$

$$AHOF = \frac{\sum_{0}^{d} HOF(d) \times F(d)}{\sum_{0}^{d} F(d)} \quad \text{(d)=deflection}$$

The HOF at each deflection is computed from balancing the moments acting on each load cell with the total moment acting on the barrier. The AHOF is then averaged using the F (d) data as a weighing function. The reason why F (d) data was used as the weighing function in this study is that the height of force could be strongly affected by the Force-Deflection characteristics in the full width barrier test. Especially, the contact force of engine with load cell wall could act the important role for the AHOF analysis. The crush based AHOF is helpful to realize the vehicle structure and the location of the engine.

The AHOF for the LTV was compared with that for SUV as a predictable parameter of the overriding phenomenon. Figure 5 shows a plot of vehicle weight versus AHOF. The AHOF for the SUV and the LTV is generally higher than for the passenger cars. However, the AHOF for the LTV indicated similar value to that for the SUV. Thus the AHOF could not discriminate the overriding phenomenon of the LTV.

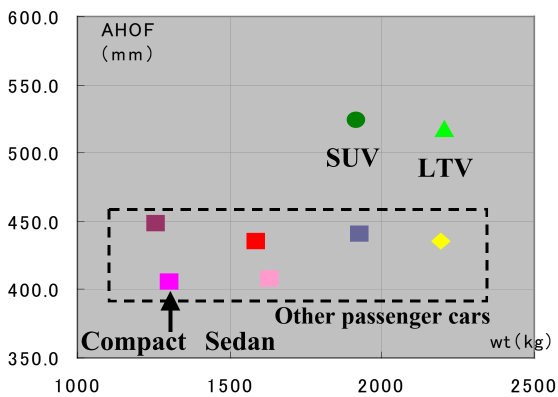


Figure 5. Vehicle weight vs AHOF

The variation on the HOF-Deflection curve was analyzed in detail. The HOF for the passenger car, SUV and LTV in the full width rigid barrier test are shown in Figure 6 as a function of deflection.

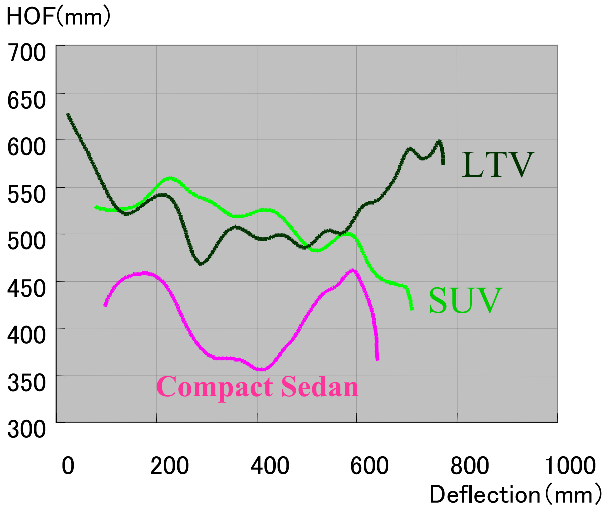
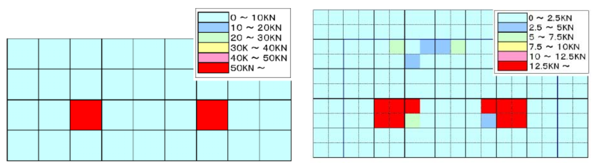
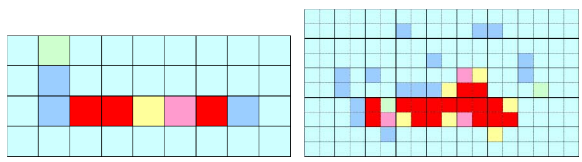


Figure 6. HOF-Deflection curve

Higher HOF values are indicated for the SUV within 200-500 mm at the HOF-Deflection curve. In order to investigate the relationship between the overriding and the HOF, each load cell output at 200-500 mm was investigated. The force distribution derived from the barrier load cells at 300 mm and 400 mm on HOF-D curve is shown in Figure 7. The test data for the LTV was from 36 load cells, and that for the SUV was from 180 load cells in this study. An important point to emphasize is that the 36-barrier load cell is about twice as large as 180-barrier load cell. If it sees roughly, similar force distribution was seen in the load cell output for both vehicles. The force distribution for the LTV at 300 mm demonstrates two of the main load paths clearly; these are the two longitudinal members.



Barrier force distribution at 300 mm on F-D curve



Barrier force distribution at 400 mm on F-D curve

Figure 7. Barrier force distribution for LTV and SUV.

Figure 8 shows the vehicle front structure of the LTV. The vertical distance from the bottom of the longitudinal member to the ground was 479 mm. The crush force of the longitudinal member of the LTV is measured by the second row from the bottom of 36 barrier load cells, whereas it is measured by fourth row of 180 barrier load cells. In that case, the HOF computed by the 36 load cells is different from that of the 180 load cells in that the moment arms for HOF is derived from the center height of the load cell.

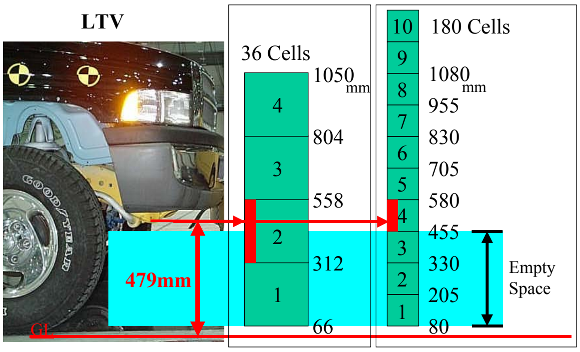


Figure 8. Relationship between the longitudinal member of the LTV and barrier load cell height.

In order to examine the AHOF, we have to clarify the influence of the load cell size first. By getting adjacent 4 load cells together in the 180 barrier load cells, imaginary 45 barrier load cells were created. (Figure 9) The total barrier load of the imaginary 45 load cells is exactly same as that of the 180 load cells. The HOF of the SUV computed by 45 load cells was compared with original HOF. It was found from the result that there was a considerable variation of the HOF that comes from the different load cell size. The result shows that the load cell size affects greatly the HOF because of the difference in the center height of the load cells. (Figure 10)

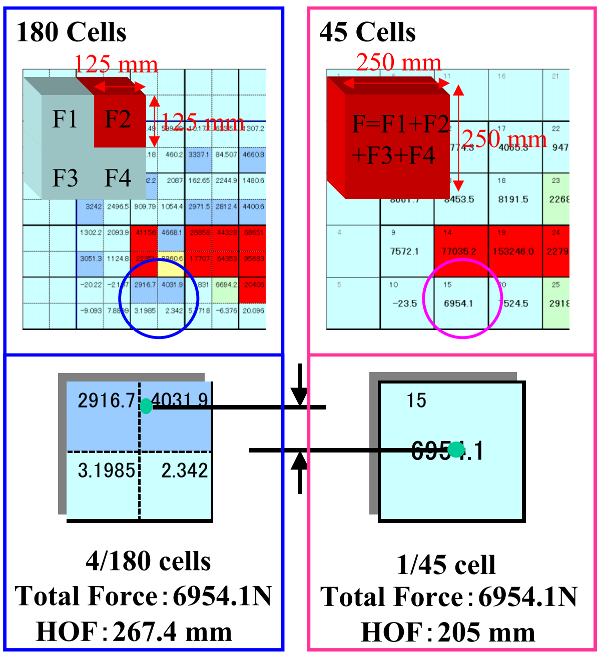


Figure 9. Combination of the load cell

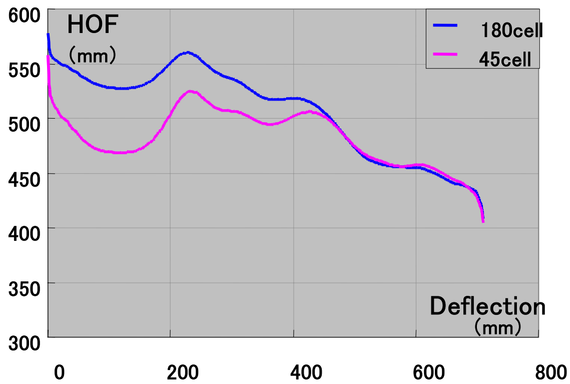


Figure 10. HOF of the different load cells size.

Let us now return to the discussion of the overriding phenomenon. It is important to note that the difference of load cell size affects the AHOF analysis, as stated above. Since 36 load cells are about twice as large as 180 load cells, 36 load cells were divided into imaginary 144 load cells tentatively. The measured barrier forces for the LTV from the 36 load cells were assigned to the imaginary 144 load cells. Assuming that the main reason for the overriding is caused by the structural mismatch between the main load paths for energy absorption, barrier load analysis was focused on the longitudinal member of the LTV. The bottom of the longitudinal member of the LTV was 479 mm in height; therefor it is reasonable that the 3rd row from the ground in the imaginary 144 load cells does not contact with the longitudinal member. The barrier force distribution was reflected according to the above reason, and the result is shown in Figure 11.

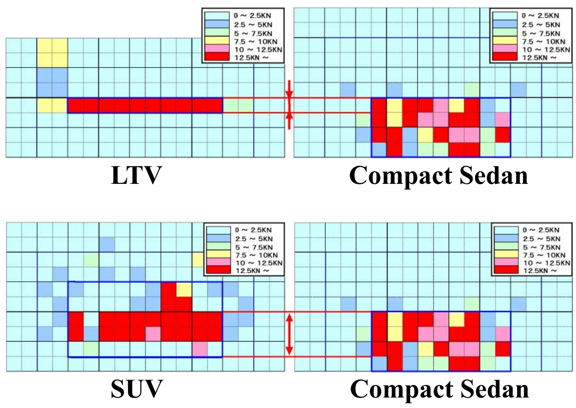


Figure 11. Force distribution between the LTV and the passenger car at 400 mm crush.

Compared with the SUV, only the two longitudinal members of the LTV place any significant force on to the load cell wall, and this was very localized. This was far from ideal and indicates a potentially aggressive structure. The SUV had a sub-frame as an extra load path, which provided a much more homogeneous force distribution. The force distribution of the LTV in height indicates that the amount of overlap for the structural interaction between the LTV and passenger car was only approximately 1 load cell row. It is quite likely that this poor interaction area for the interface force leads to the overriding of the LTV. Therefore, the vertical width of interaction area should be considered to be a geometric compatibility index.

Generally speaking, as the AHOF of the LTV becomes high, the structural interaction would decrease between LTV and passenger cars in frontal impact. From this point of view, one may say that the AHOF could be a geometric index for compatibility. However no overriding phenomenon was seen in the SUV-to-Car impact with reasonable interaction area between two vehicles, thus the interaction area could also be one of the important factors to prevent overriding. The SUV/LTV-to-vehicle impacts in this study revealed that the reasonable extent of the interaction area should be taken as a geometric compatibility index. (Figure12a,b)

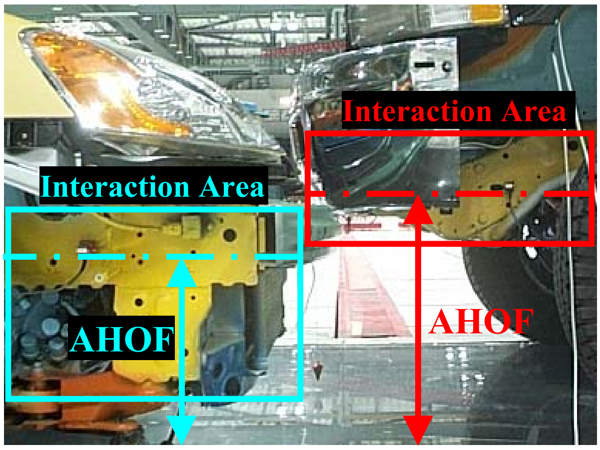


Figure 12a. AHOF and Interaction Area.

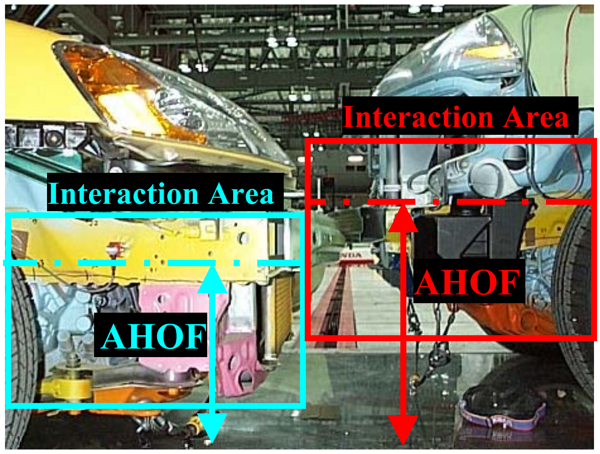


Figure 12b. AHOF and Interaction Area.

Ideally, the AHOF and the interaction area should be matched completely to absorb energy, however it is necessary to study the reasonable extent of the interaction height and area. The geometrical alignments of the bumpers and the longitudinal members of passenger cars in the US fleet are derived from the US bumper standard. Additionally, a lot of passenger cars in other countries are having the similar longitudinal members in height, because they have a US model. This concentration of the longitudinal member in height provides an opportunity to encourage the resolution of the interaction area. SUV/LTV should respond to support this bumper height range that prevent partner cars from being overridden.

Stiffness Compatibility

The force concentration causes a local penetration into partner vehicle, which is far from an ideal and indicates a potentially aggressive structure. Vehicle front-end structures must be homogeneous to avoid a “fork effect”, and must absorb a sufficient energy to reduce a passenger compartment intrusion. In order to assess the stiffness compatibility, full with barrier load cell data was analyzed by using the coefficient of variance (CV) [7].

CV = Standard Deviation / mean

The localized barrier forces were seen in the LTV test, however the number of 36 load cells used in the NCAP test is not acceptable for the CV analysis, therefor an example of another case was selected to assess stiffness compatibility. The lateral structural mismatch between vehicles can be often seen in the vehicle-to-vehicle impact that has a single load path for energy absorption. Here is another example of single load path car shown in Figure 13a.

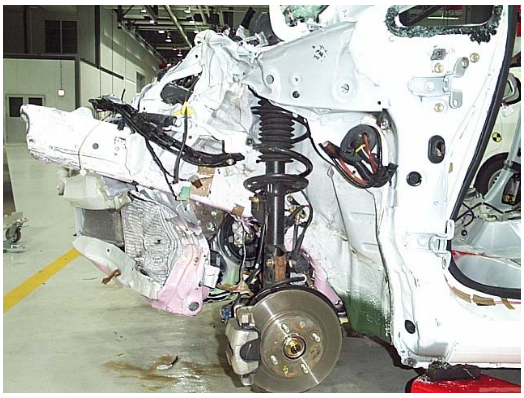
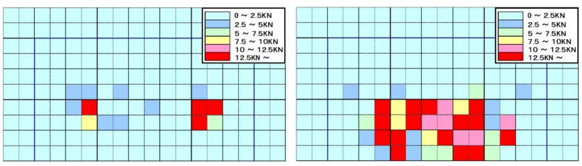


Figure 13a. Single load path Car A after vehicle-to-vehicle impact test.

Figure 13b. Multiple load paths Car B after vehicle-to-vehicle impact test.

Figure 13b shows a Car B that has a multiple load path for energy absorption and more homogeneous structure in vehicle front. A subjective visual inspection of force distribution on each load cell shows a force concentration of the higher load for the car A caused by the single load path. The CV was computed for the Car A and the Car B and shows substantially higher values for the Car A.



Barrier force distribution at 400 mm on CV-D curve

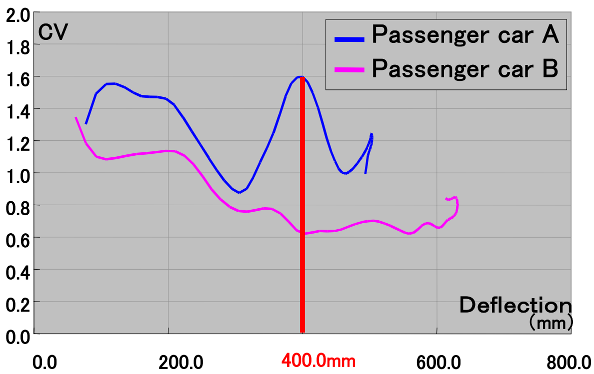


Figure 14. The CV for the Car A and the Car B

To demonstrate the potential of this analysis, the load cell data for more compatible family cars have been compared to those for less compatible vehicle. To make direct comparison of the results of the CV possible, overall average was computed using the deflection data as a weighing function.

As shown in Figure 15, Passenger cars and Minivans were found to be the similar homogeneous vehicle category with a CV from CV = 0.75 to CV = 1.2. The CV of SUV was obviously higher and ranged from CV = 1.25 to CV = 1.3. The difference in these values demonstrates the potential of this parameter as an index to evaluate the stiffness compatibility of vehicle front structure.

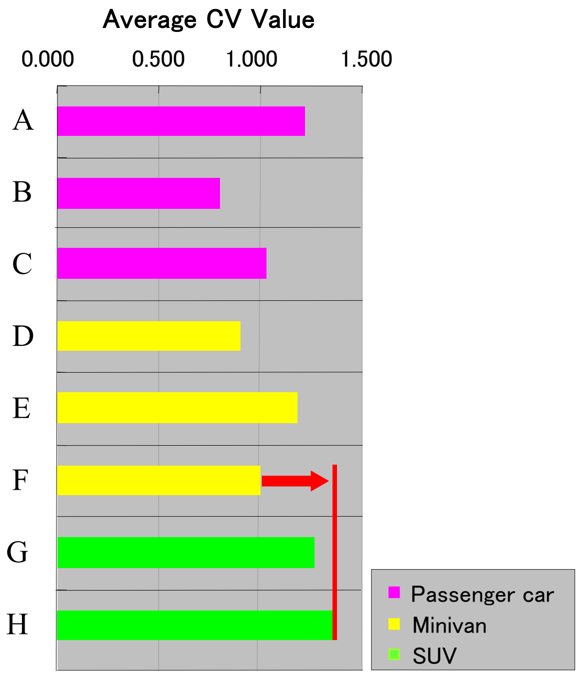


Figure 15. Average CV for various vehicles.

Here the question now arises: the SUV-H and the Minivan-F have almost same framework in the vehicle front structure (Figure 16), however SUV-H with CV = 1.3 was much higher than that of Minivan-F with CV = 1.0. Assuming that the similar framework provides the similar CV value, the question is why those two CV values were very different. Since the major difference between the two vehicles is a ride height, the influence of the ride height was investigated in the first place.

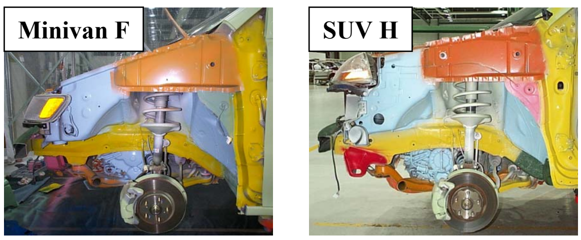


Figure 16. Vehicle front structure of Minivan F and SUV H.

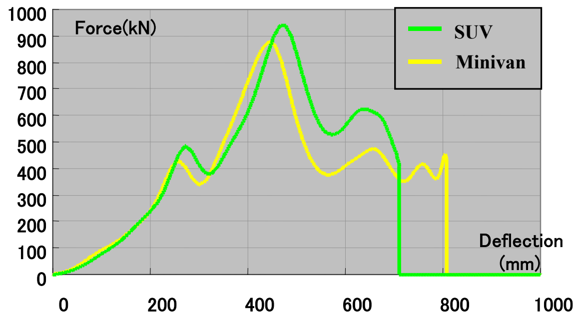


Figure 17a. Force-Deflection curve.

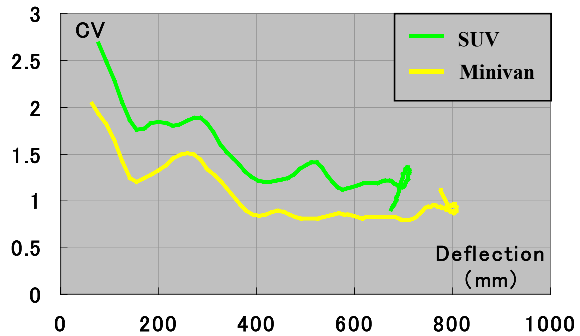


Figure 17b. CV-Deflection curve.

Figure 17a,b shows the F-D and CV-D curve for the SUV-H and the Minivan-F. The F-D curves for both vehicles showed similar trend in early stage of the impact on the ground that they have the similar framework, whereas the CV for both vehicles showed considerable difference. The difference of the CV value has resulted from the assessment area that was used for computing the CV. The assessment area is identified with the area that at least one load cell in the outside row or column was indicated a peak force greater than 5 kN in the impact. The difference of the assessment area was derived from the different ride height; namely the higher SUV has the larger assessment area. The mean value of the barrier force of the SUV-H was lower than that of the Minivan-F because of its larger assessment area. The low mean value of the barrier force causes the high CV value. That is the reason why the CV for the SUV-H has become higher than that for the Minivan-F as a consequence.

The CV is too sensitive when the mean value of the force is low in early stage of impact, because the gap between the mean force and higher force causes large standard deviation. The CV for the SUV-H and the Minivan-F were computed again with the assessment area that was defined at each deflection, then the results appear in Figure 18. By using this method, the CV value of the SUV-H became similar to that of the Minivan-F. In other words the homogeneity of the vehicle front structure was assessed more precisely.

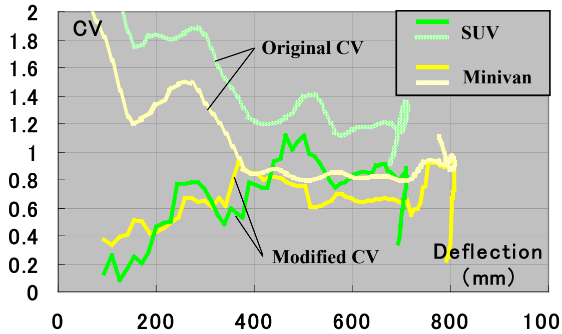


Figure 18. CV computation for each deflection.

A local penetration issue would be controlled by homogeneity assessment. However, in addition to homogeneity assessment, there is one other thing that is important for stiffness compatibility. There is no doubt about the fact that heavier vehicles have a higher global stiffness than lighter vehicles, because heavier vehicles must absorb their kinetic energy in approximately same crash distance in a fixed barrier test. The stiffness of the vehicle is somewhat related to its mass. In order to assess the stiffness matching between vehicles, some candidate test procedures have been proposed. A further research direction of this study will be to examine those test procedures to clarify reasonable global stiffness. As discussed in geometrical compatibility, it is important for stiffness compatibility that the stiffness within the interaction area would be investigated carefully with regard to frontal impact.

MDB-TO-CAR TEST

Various test procedures are being used to evaluate the self-protection of occupants provided by production vehicles in frontal crashes. The offset deformable barrier (ODB) test is designed primarily to reproduce the deformation patterns seen in real world crashes, accordingly addressing intrusion induced injuries. In contrast, the full width barrier test is designed to provide information relating to deceleration pulse induced injuries.

The NHTSA has been developing an MDB test to evaluate both self-protection and the compatibility of the vehicle [8]. A fixed mass MDB test allows the mass ratio effect to be taken into account, and it can generate a realistic delta V and vehicle deceleration pulse. One of the goals to use the MDB is to reproduce a vehicle-to-vehicle crash response, deformation of the vehicle and occupant kinematics seen in the real world type crashes.

One of the concerns of the MDB testing is its proneness to overriding issue, and IHRA WG report says that the overriding was greater when a vehicle was stationary [(2), (9)]. Offset frontal vehicle-to-vehicle test with same two passenger cars was carried out to confirm this issue according to the test configuration shown in Figure 19. In this test, the initial velocity of striking vehicle was chosen at 112 km/h and the struck vehicle was stationary.

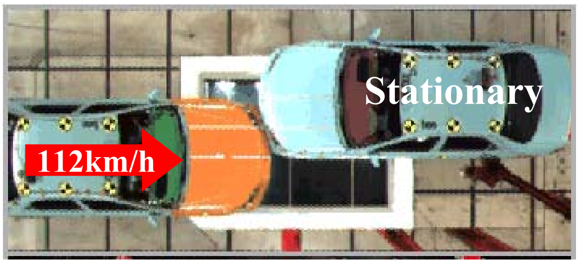


Figure 19. Car-to-Car test configuration.

In this test, injury measures of the dummies in the struck vehicle was the same level as those in the striking vehicle, therefore the injury measures did not indicate either vehicle being overridden. The result of the intrusion indicated that the deformation of the struck vehicle was slightly greater than that of the striking vehicle.

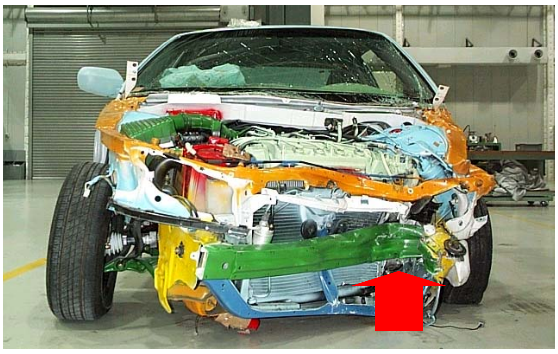


Figure 20a. Deformation mode of the striking car (front).

Figure 20b. Deformation mode of the struck car (front).

Figure 20c. Deformation mode of the striking car (side).

Figure 20d. Deformation mode of the struck car (side).

The different bending mode of the bumper beam was observed in both vehicles; to put it briefly, the bumper beam of the striking vehicle bent downward, and that of the struck vehicle bent upward to the contrary. (Figure 20a,b) The upper rail of the struck vehicle was more deformed than that of the striking vehicle and the lower rail of both vehicles demonstrated a different failure mode. (Figure 20c,d) There was no obvious over-riding phenomenon during the test, however the deformation profile of the struck vehicle showed the signs of being over-ridden. It was found from the result that the proneness of overriding to the stationary vehicle holds true, consequently the MDB-to-Car test has been conducted with both vehicles moving to prevent overriding.

Another issue for the MDB test is the bottoming out of the defomable face. The Federal Motor Vehicle Safety Standard (FMVSS) 214 MDB was studied in our previous study and the honeycomb bottoming out phenomenon was observed. There is no bottoming out in vehicle-to-vehicle impact; therefore the barrier must be design to avoid this phenomenon.

A Progressive Deformable Barrier (PDB) has a depth of 700 mm and was developed to avoid bottoming out [10]. Judging from the above, the PDB was selected as one of the candidates of deeper honeycomb, and MDB-to-Car test was carried out with the deformable face of PDB. Figure 21 shows the test MDB-to-car test configuration. The 1362 kg MDB was used to strike the compact sedan in 40% offset collinear with both vehicles traveling at a speed of 56 km/h. In the MDB-to-Car test, Hybrid Ⅲ 50th percentile male dummies were used to evaluate the injury levels for the driver and passenger.

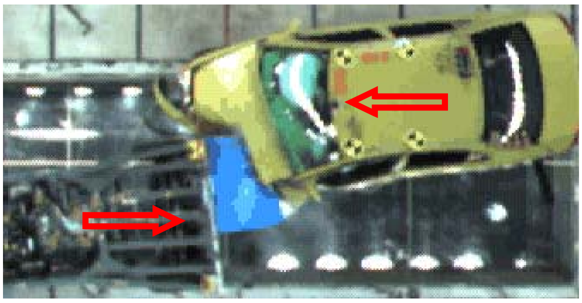


Figure 21. MDB-to-Car test configuration.

This preliminary MDB test was conducted to compare the vehicle deformation and injury levels in an equivalent vehicle-to-vehicle test. Target compact sedan was subjected to three energy equivalent crash tests shown in Table 3, and results were compared.

Table 3.
Test matrix

Test	Test speed	Total Kinetic Energy	Offset Ratio
Car-to-Car	50 km/h	4451 kN･m	50%
MDB-to-Car	56 km/h	4312 kN･m	40%
ODB-to-Car	64 km/h	4262 kN･m	40%

The deceleration pulses of the target vehicle in the vehicle-to-vehicle collinear test, in the MDB test, and in the ODB test are shown in Figure 22.

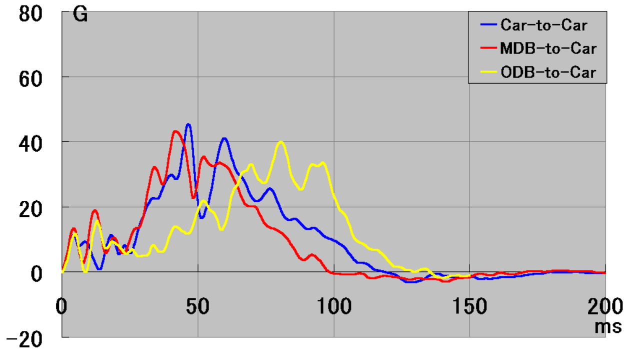


Figure 22. Comparison of Deceleration Pulses.

The overall deceleration pulse shape and timing in the MDB 40% test was generally similar to that in the vehicle-to-vehicle 50% test, in contrast the peak deceleration occurred approximately 40 millisecond later in the ODB 40% test. This figure shows that the MDB test matched the vehicle-to-vehicle response very well, whereas the crash pulse resulting from the ODB test does not appear similar to the vehicle-to-vehicle crash pulse.

Figure 23 and 24a,b show the comparison of dummy responses for the three crash test conditions for the compact sedan. Injury Assessment Reference Values (IARV) were used to normalize the injury measures. These reference values are defined in FMVSS 208 except for the tibia index that uses a reference value of 1.3, as defined by the EU96/79 standard.

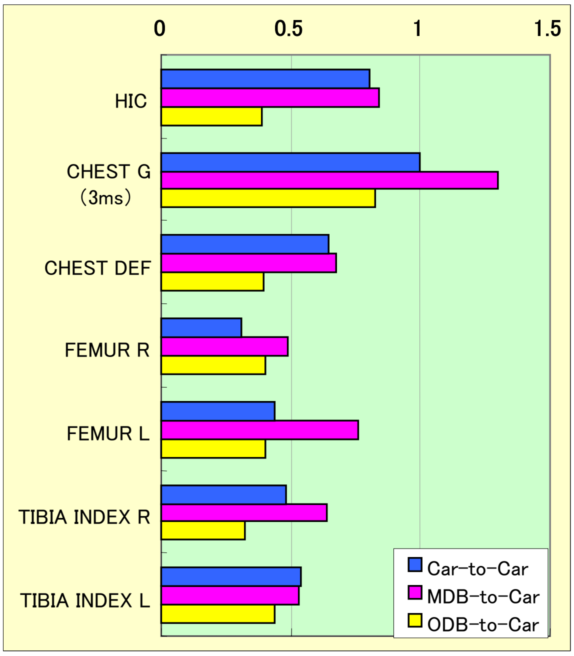


Figure 23. Comparison of IARV

A very good match was observed between the Car-to-Car dummy responses and the MDB test. This MDB test is slightly more severe than corresponding Car-to-Car test, resulting in higher vehicle response and higher dummy head, chest and femur response. The ODB test responses was compared to the Car-to-Car response and MDB-to-Car test. Comparing dummy responses from Figure 23 shows much lower dummy responses for all major injury measures, even though the ODB is at similar impact energy.

This holds especially true for the head and chest response comparisons. (Figure 24a,b.) This match is expected since the MDB test was designed to reproduce the vehicle-to-vehicle test mode.

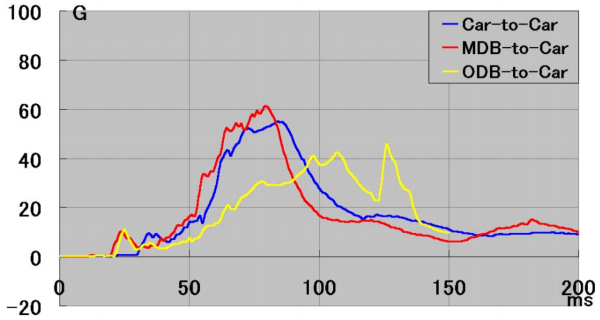


Figure 24a. Comparison of Driver Head Deceleration Pulses.

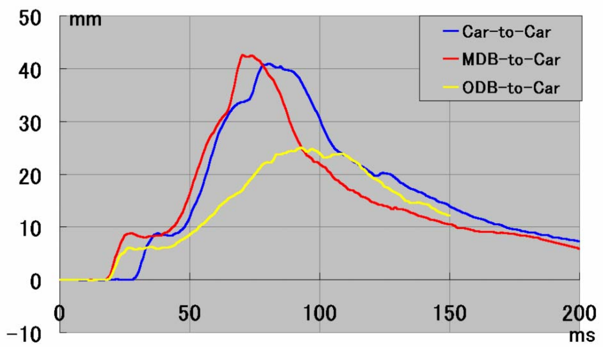


Figure 24b. Comparison of Driver Chest Deflection Pulses.

Figure 25 and 26 show the overall vehicle deformation. A very good reproducibility was observed with regard to the vehicle deformation as well as dummy responses. These results lead us to the conclusion that Car-to-Car crashes can be better reproduced using an MDB-to-Car test. It is thought that this MDB test will allow realistic evaluation of compatibility.

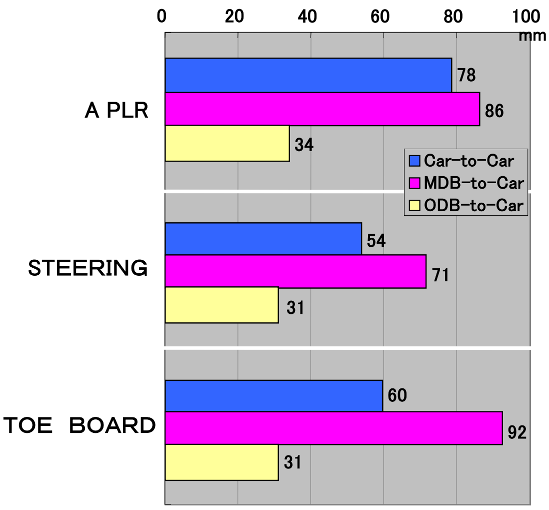


Figure 25. Comparison of vehicle deformation

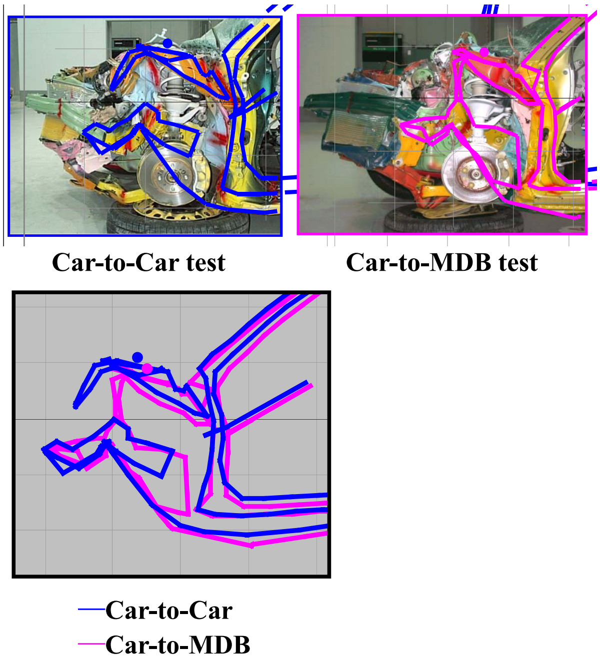
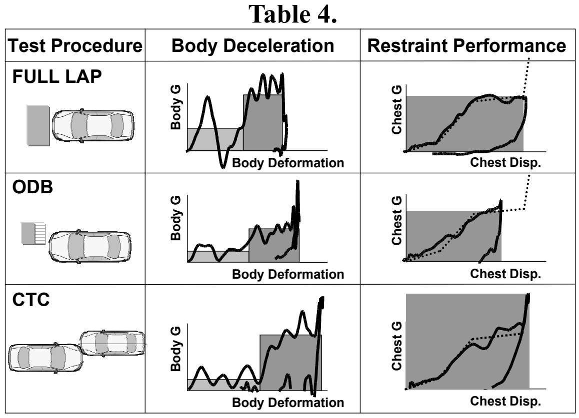


Figure 26. Comparison of 3-D measurement data of the Compact Sedan.

The result of Car-to-Car crash depends on the characteristics of the two opposing vehicles. Although Car-to-Car crashes have a low initial deceleration similar to ODB crashes, they also produce extremely high input loads into the cabin and high deceleration levels in the second half of the crash. As a result, the crash energy translated to the occupant by Car-to-Car offset crash is actually equal to or greater than that for a full width barrier test. However, the cabin survival space is significantly reduced compared to the other two tests, and there are many cases where this causes secondary collisions with interior parts which worsen the occupant injury severity [11]. (Table 4)

Table 4.



Relationship between Body Deceleration and Deformation and Occupant Injury Severity by Crash test

An examination of evaluation test procedure that combine these characteristics shows the moving deformable barrier (MDB) crash test to be ideal. The MDB test procedure is currently one test method which models Car-to-Car crashes from the dual perspective of body deceleration characteristics, which control occupant injury severity, and occupant survival space. Test results show that the body deformation and deceleration of the test vehicle closely approximated those in an actual Car-to-Car crash. As a result, it was found that vehicle-to-vehicle crashes might be better reproduced using an MDB-to-Car test as opposed to a conventional fixed barrier test.

DISCUSSION

The barrier load data analysis calls for further investigation. The full width rigid barrier test is too sensitive to the inertia force when hard structures hit with the rigid wall. The load cell data in the rigid barrier test should be compared with that in the full width deformable barrier test proposed by the Transport Research Laboratory (TRL) with respect to the AHOF and the CV [12].

In the case of SUV/LTV-to-Car offset crashes, the target vehicle experienced a lower deceleration level in the early stage of the impact (up to 30 ms) and a higher deceleration in the later stage of the impact. The lower deceleration pulse can be reproduced by the ODB test and the higher deceleration pulse can be reproduced by the full width barrier test. However, the combination of initial low deceleration and the following higher deceleration, which causes severer injury levels, will not be reproduced by those test procedures. Nothing will reproduce the realistic deceleration pulse in the vehicle-to-vehicle impact better than that in the MDB test. A further research direction of this study will be examining if the MDB characteristics will allow realistic evaluation of compatibility in various countries. MDB test procedure should be considered varying the crash angle, speed, offset ratio and other factors of the vehicle fleet in each country. Then, these results should be used to determine vehicle specifications that can improve occupant injury severity and metrics for the future evaluation of compatibility.

CONCLUSION

This report has examined the compatibility between SUV/LTV and passenger cars in vehicle-to-vehicle crash tests.

1. The LTV overrode the passenger car during the LTV-to-Car frontal offset crash. Significant deformation and dash intrusion were observed in the target vehicle in the LTV-to-Car impact compared to that in the SUV-to-Car impact. This was caused by vertical structural mismatch between the two vehicles. In the studied frontal SUV/LTV-to-Car impacts, it was found from the result that good structural interaction was a fundamental requirement to crash compatibility.
2. In order to improve compatibility, it is necessary to develop test procedures that can evaluate the various criteria for both aggressivity and self-protection. Our development activity is being focused on two test procedures, namely one is a full width barrier test with load cells and the other is an MDB test.
3. The load cell data in the full width barrier at 56 km/h was analyzed to assess the structural interaction. The AHOF could become a geometric compatibility index and interaction area should also be taken as a compatibility index at the same time. As one of the indices for stiffness compatibility, the CV could evaluate homogeneity of the vehicle front structure. However, further study for the calculation method of the CV is needed to assess the homogeneity more precisely.
4. It was clear that the barrier load cell size affects seriously the result of the AHOF and the CV. Therefore, barrier load cells should be smaller and identical size among various laboratories in order to assess these compatibility indices correctly.
5. The issues of bottoming out the honeycomb and overriding of the MDB were improved in this study. It was found that the MDB test could reproduce the body deformation and deceleration observed in actual vehicle-to-vehicle impact by using a PDB as a deformable face. The resulting vehicle deformation, vehicle deceleration and occupant injury severity matched closely with actual vehicle-to-vehicle tests. The MDB would address deceleration-induced injuries in addition to contact-induced injuries.
6. Combining the full width barrier test and the MDB test has a possibility to provide an improved compatibility. This combination of the test procedures can evaluate the vehicle characteristics from vehicle front-end homogeneity to passenger compartment strength. The MDB provide more flexibility to reproduce vehicle-to-vehicle crash, hence the MDB test would offer the best overall coverage of real world accidents.

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