STUDY OF LOAD CELL MDB CRASH TESTS FOR EVALUATION OF FRONTAL IMPACT COMPATIBILITY

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ABSTRACT

The purpose of this study is to evaluate load cell moving deformable barrier (LCMDB) tests as a means of assessing frontal impact compatibility between vehicles. An LCMDB is employed to enable assessment of relevant partner-protection characteristics in addition to self-protection performance in a front-to-front crash test. The ability to control key characteristics of compatibility in LCMDB tests enables force measurements on the load cell wall to be used to assess structural interaction, frontal force level and passenger compartment strength.

In this study, LCMDB tests have been conducted with various deformable elements to determine how well they correlated with fixed barrier tests or vehicle-to-vehicle tests. Firstly, barrier load cell data measured in a full-frontal LCMDB-to-vehicle crash test are compared with data measured in a full width deformable barrier (FWDB) test at 56 km/h. In addition, some compatibility metrics such as average height of force (AHOF) and force distribution are compared. Secondly, an offset-frontal LCMDB-to-vehicle crash test has been conducted to evaluate the passenger compartment strength for small cars in an overload condition. Force measurements of the load cell wall are compared with data obtained from an offset deformable barrier (ODB) test at 64 km/h. Finally, an oblique-frontal LCMDB-to-vehicle crash test has been conducted and the test results are compared with vehicle-to-vehicle tests and with fixed oblique barrier tests at 50 km/h in terms of the vehicle and occupant kinematics.

The study has shown that the LCMDB-to-vehicle test offers a realistic simulation of the effect of differences in mass in vehicle-to-vehicle impacts, and enables compatibility metrics to be evaluated.

INTRODUCTION

Frontal vehicle-to-vehicle collisions are still the most common accident type causing fatal or serious injuries; hence vehicle crash compatibility in frontal impact may offer the greatest potential to enhance a vehicle occupant's safety. One of our research goals for enhancing frontal impact compatibility between vehicles is to develop new test procedures which would lead vehicle structures to be more compatible in frontal collisions. Compatibility performance is determined both by self-protection performance and aggressivity; therefore compatibility assessment must have test methods and performance criteria for these two requirements. The authors examined a set of test procedures for frontal impact compatibility to evaluate relevant vehicle characteristics of compatibility including a moving deformable barrier (MDB) test method [1, 2]. The MDB test is currently one test method used to simulate vehicle-to-vehicle crashes from the dual perspective of body deceleration characteristics, which control occupant injury severity, and occupant compartment space. The MDB test allows the mass ratio effect to be taken into account, and it can generate a realistic delta V and vehicle deceleration pulse. The approach of using an MDB test can produce relatively realistic vehicle-to-vehicle crash response, deformation and occupant kinematics, thus the MDB more adequately represents what happens in vehicle-to-vehicle type accidents. The work described in this paper updates the MDB test method with data obtained from employing a load cell MDB (LCMDB) to evaluate relevant characteristics for frontal impact compatibility. The ability to control key characteristics of compatibility in LCMDB tests enables force measurements on the load cell wall to be used to assess structural interaction, frontal force level and passenger compartment strength. This paper provides a comparative analysis between the fixed barrier tests and the LCMDB tests. Three major fixed barrier test conditions were selected based on commonly conducted international crash testing, which are the full width deformable barrier (FWDB) test, offset deformable barrier (ODB) test and fixed oblique barrier (FOB) test.

MDB-TO-VEHICLE FULL-FRONTAL CRASH TESTS

In the US fleet, incompatibility between LTVs and passenger cars has been identified through an accident analysis [3]. One issue of the incompatibility between LTVs and passenger cars is based on a lack of structural interaction due to geometrical differences. Barrier load cell data in the US New Car Assessment Program (US-NCAP) was investigated by the National Highway Traffic Safety Administration (NHTSA), and some compatibility metrics such as the AHOF, initial force and force distribution were measured on the load cell wall (LCW) [4, 5]. Those parameters may control structural interaction and frontal stiffness, which would be beneficial in enhancing the interaction characteristics of vehicles. Therefore, a full width barrier test with a load cell wall could be a candidate test procedure to evaluate the interaction characteristics and stiffness (sometimes referred to as the “aggressivity” of vehicles). A number of parameters can be proposed and developed from the available barrier load cell data. The Transport Research Laboratory (TRL) developed a full width deformable barrier (FWDB) test and some homogeneity criteria were proposed to assess and control structural interaction. Figure 1 shows the configuration of the FWDB. Currently the deformable barrier face that is proposed by TRL has two layers. The first layer consists of a 0.34 MPa aluminum honeycomb element that is 150 mm deep, and the second layer consists of a 1.71 MPa element, also 150 mm deep. The second layer is segmented into individual blocks and is constructed so that each block is in line with each barrier load cell.

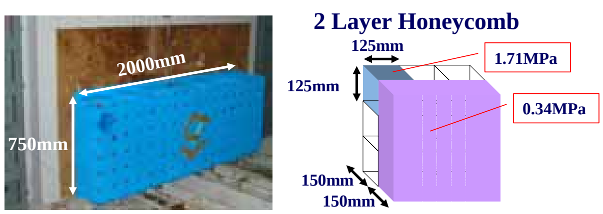


Figure 1. Full width deformable barrier test

The purpose of full-frontal LCMDB testing with the 2 layer honeycomb is to compare it with the FWDB test using measured compatibility metrics. In this study, the weight of the LCMDB was set to the same weight as the target vehicle in order to compare the test results with the FWDB test. Figure 2 shows the load cell layout of the full-frontal LCMDB test. The LCW for the MDB full-frontal impact consists of 64 load cells, with each surface area 125 x 125 mm. Unfortunately the number of the load cells was restricted by the gross weight of the LCMDB. The mass of the LCMDB was set to correspond to the subject SUV, which was about 2200 kg.

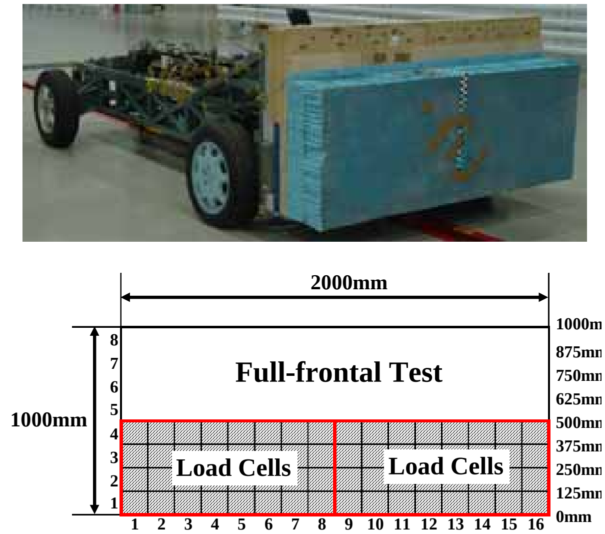


Figure 2. Load cell moving deformable barrier layout

The ground clearance of the load cell wall for the LCMDB was set at 205 mm in height in order to get the barrier load data generated by the primary energy absorption structure (PEAS) and secondary energy absorption structure (SEAS). The 64 load cells covered the US bumper regulation zone and the height of the load cells was in line with the 2nd-5th row of the fixed barrier’s LCW. See Figure 3.

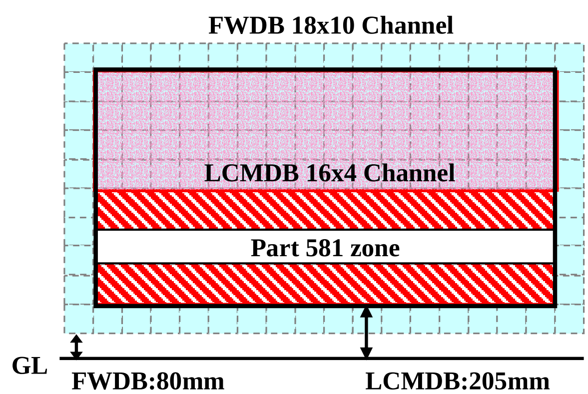


Figure 3. Comparison of load cell layout

The test program was developed with the objective of evaluating the use of an LCMDB constant energy compatibility test procedure in comparison to the FWDB test. Figure 4 compares the full-frontal impact tests among three different test configurations. In LCMDB-to-vehicle testing with a shallow deformable barrier (DB), the impact speed should be adjusted so that the kinetic energy corresponds to the vehicle-to-vehicle impact due to the shallow DB lacking an energy absorption capability. An energy equivalent full-frontal LCMDB test was conducted and the test results were compared with the FWDB test. An SUV was selected as a target vehicle to analyze barrier load cell data. An LCMDB-to-SUV impact was performed at a closing speed of 80 km/h to maintain the kinetic energy, which was equivalent to that at the FWDB 56 km/h. Hybrid III 50th percentile male dummies were used to study the injury levels for the driver and passenger positions.

Test Configuration

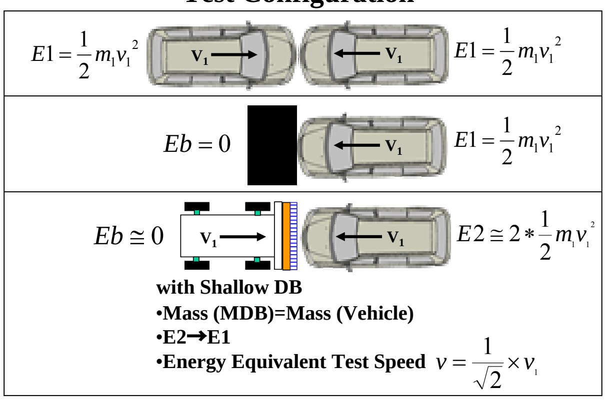


Figure 4. Energy equivalent full-frontal impacts

The deformation levels of the vehicles demonstrated similar results except slightly different deformation modes of the front side member. See Figure 5.

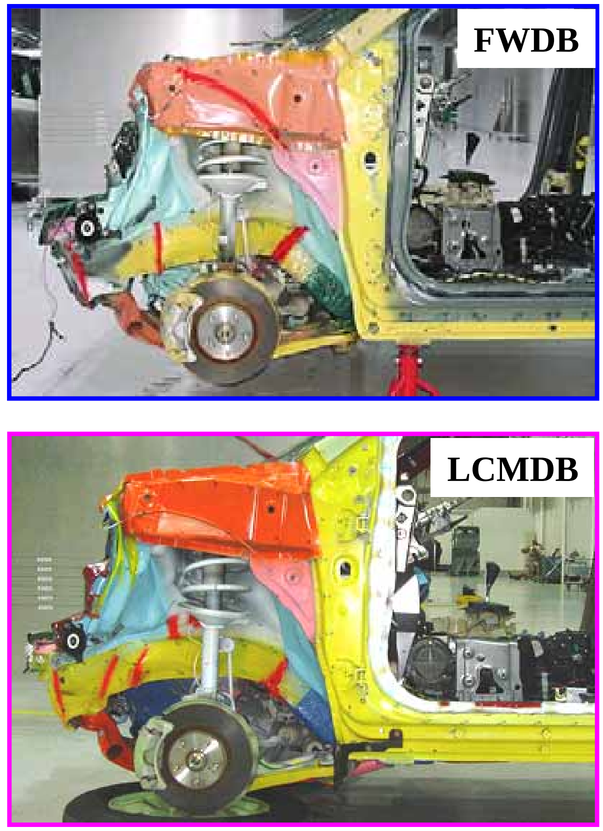


Figure 5. Comparison of body deformation modes

Figure 6 shows dummy injury levels. Similar results were also observed between the two tests.

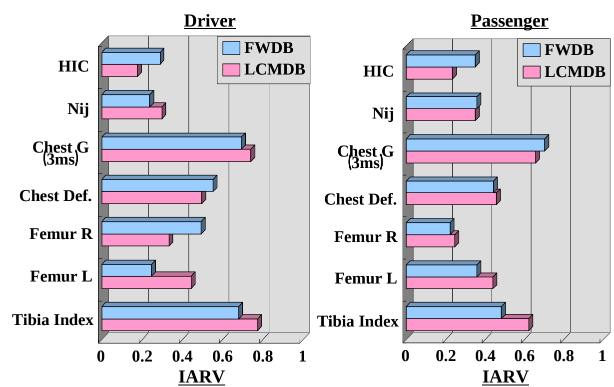


Figure 6. Comparison of injury measurements

Noticeable differences between the two tests occurred on the deceleration-time histories. The vehicle deceleration pulse in the energy equivalent LCMDB test indicated shorter duration of the crash pulse compared with the FWDB test. See Figure 7.

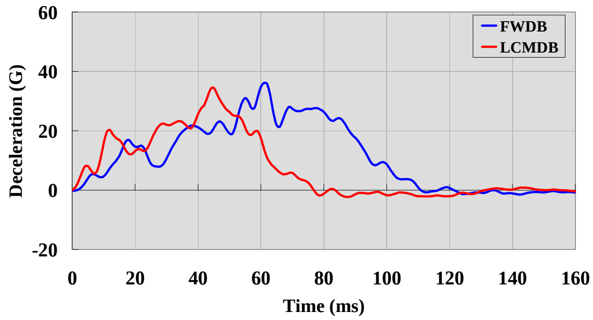


Figure 7. Comparison of body deceleration vs. time curves

Compared to the vehicle deceleration pulse, the dummy deceleration pulses in the LCMDB test demonstrated shorter crash pulses than were achieved in the FWDB test while the injury values were similar. Figure 8 shows the dummy chest deceleration pulse as an example of the dummy response.

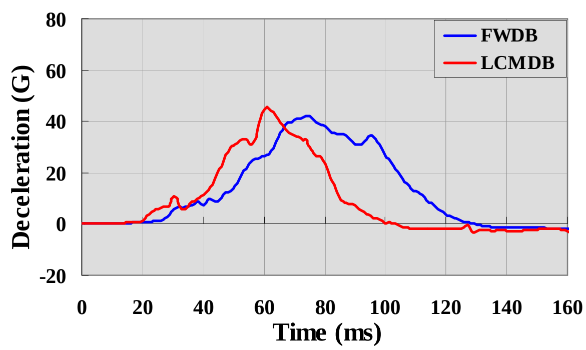


Figure 8. Comparison of chest deceleration pulses of driver dummy

An interesting comparison can be made by inspection of the deceleration vs. displacement curves. The two deceleration-displacement curves follow each other quite closely until the end of the impact. This illustrates the overall structures were behaving in a similar way in both tests, which equates to reproducibility, which is a prime requirement for an energy equivalent test. See Figure 9.

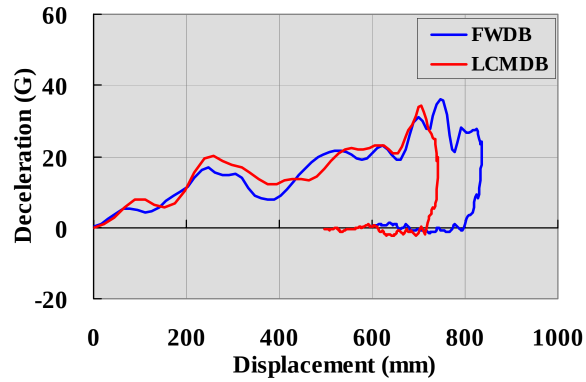


Figure 9. Comparison of body deceleration vs. displacement curves

In principle, the vehicle deceleration pulse determines the relative movement between the vehicle and the dummy. The dummy displacement relative to the vehicle generates a tension force on the seatbelt and the dummy deceleration is produced by the seatbelt tension force. The deceleration-displacement curves for the driver pelvis clearly proved this theory. See Figure 10.

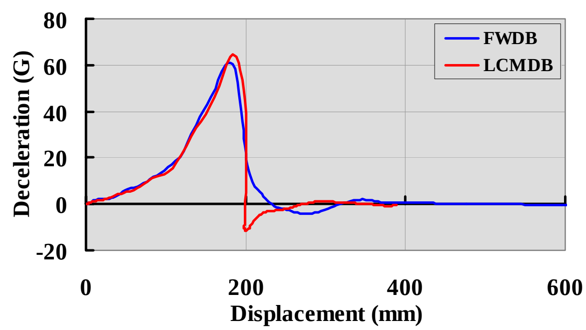


Figure 10. Comparison of dummy pelvis deceleration vs. displacement curves

However, the deceleration curves for the driver head were different between the two tests. See Figure 11. This may be because an airbag reaction force, which is determined by the internal pressure of the airbag, is dependent on time; whereas the seatbelt tension force is dependent on displacement as a factor. In an energy equivalent LCMDB test, the deceleration vs. time histories should be checked if such data would influence test results.

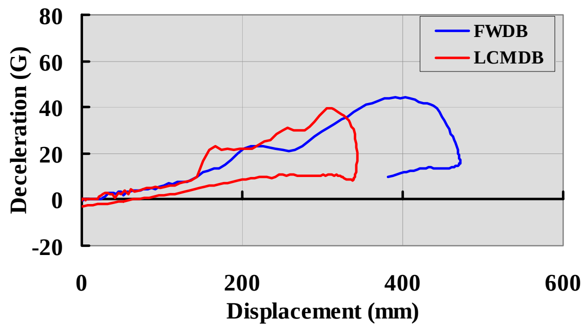


Figure 11. Comparison of dummy head deceleration vs. displacement curves

Next, the barrier load cell data was compared between that obtained in the FWDB test and that in the LCMDB test. Fairly good correlation was seen in the total barrier load cell data. See Figure 12.

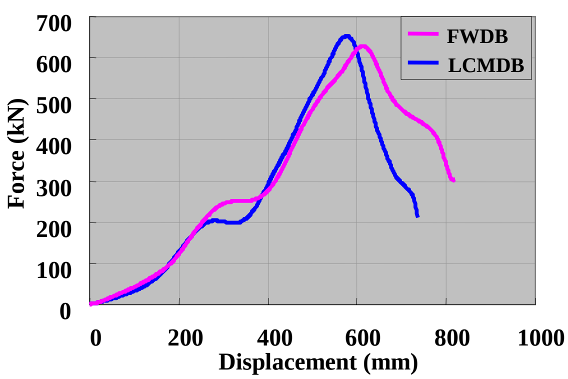


Figure 12. Comparison of total barrier force

Moderate correlation was seen between the two barrier load cell data sets; however, the major differences in the load cell data were caused by the bottoming out of the deformable barrier in front of the side members. See Figure 13.

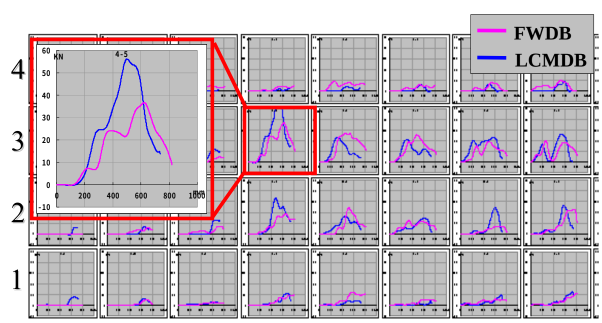


Figure 13. Comparison of barrier force in each load cell (left side), Force (kN) vs. Displacement (mm)

The time-based contour graphs were compared between the two tests. Considerably different contour graphs were seen in the time-based graph. See Figure 14.

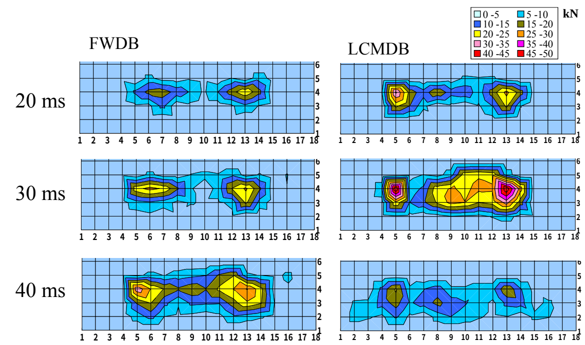


Figure 14. Comparison of time-based contour graphs

However, displacement-based contour graphs illustrated more similar results due to similar deformation modes of the body. See Figure 15. Therefore, barrier load data analysis was made in the displacement-based barrier load data in addition to the time-based load cell data analysis in this energy equivalent test.

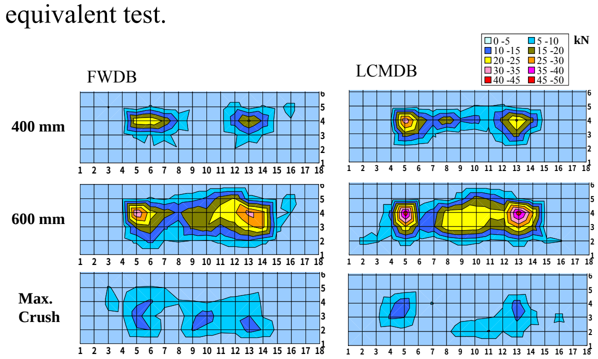
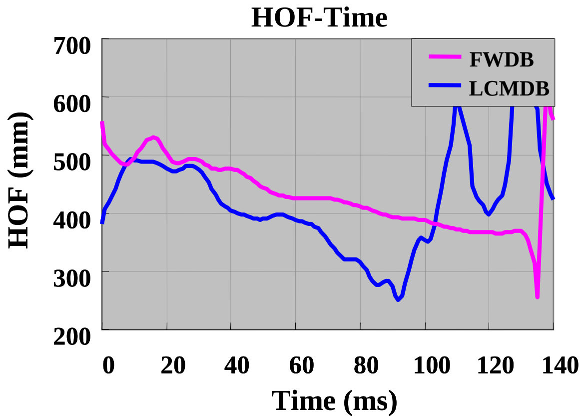


Figure 15. Comparison of displacement-based contour graphs

The height of force (HOF) was computed for each time step and for each displacement step during the impact. The HOF-displacement graph in the LCMDB test looks similar to that in the FWDB test compared with those in the HOF-time graph. Moreover the HOF-displacement graph visually told us what structure has influenced the HOF during the impact. As can be seen in the picture, the engine loading might have decreased the HOF. See Figure 16.

$$HOF(t) = \frac{\sum_{1}^{cells} Fi \times Hi}{\sum_{1}^{cells} Fi} \quad \text{t : Time step}$$



$$HOF(d) = \frac{\sum_{1}^{cells} Fi \times Hi}{\sum_{1}^{cells} Fi} \quad \text{d : Displacement step}$$

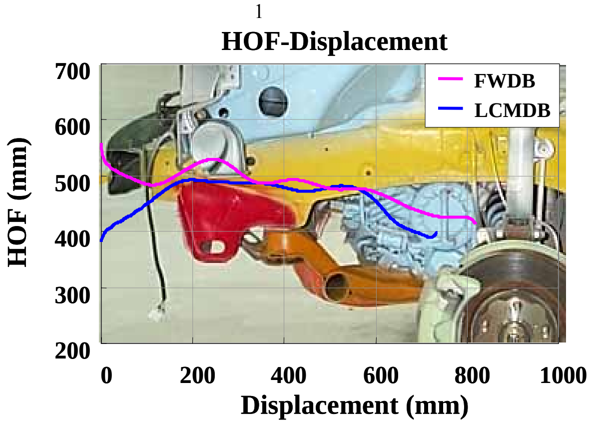
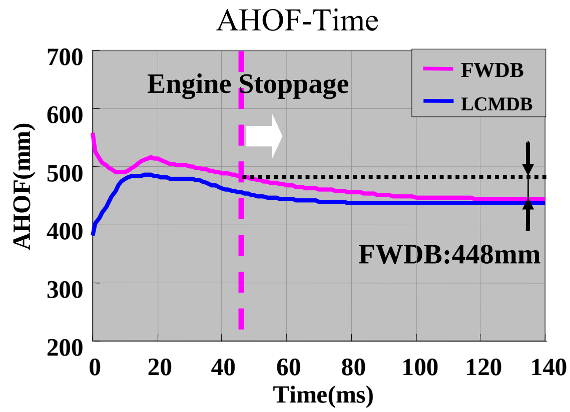


Figure 16. Comparison of height of force (HOF)

$$AHOF = \frac{\sum_{0}^{t} HOF(t) \times F(t)}{\sum_{0}^{t} F(t)}$$



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

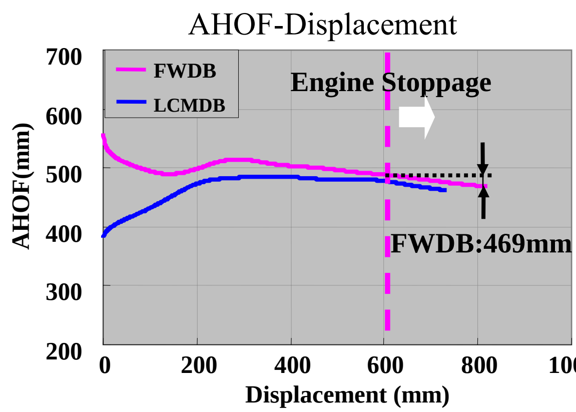
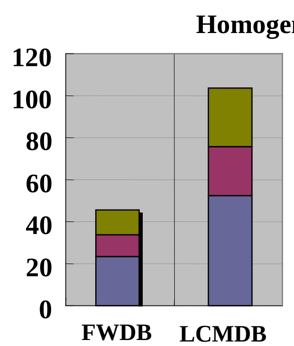


Figure 17. Comparison of average height of force (AHOF)

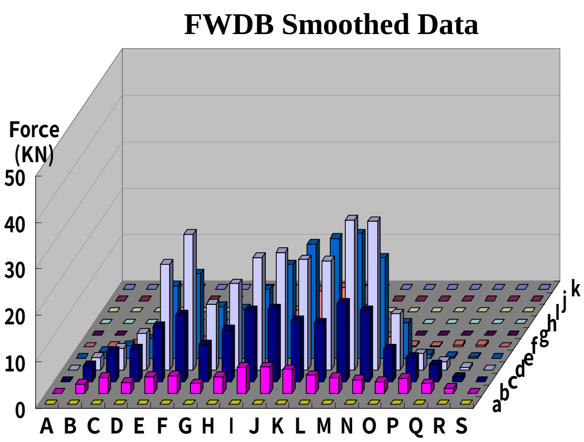
The average height of force (AHOF) is computed using the force data as a weighting function. Barrier forces transmitted through the engine may have greater influence on time-based AHOF because the time after engine stoppage was relatively long. On the other hand, displacement-based HOF may have less of an influence on engine loading because the displacement after engine stoppage was relatively short. In fact the time-based AHOF in the FWDB test indicated a 21 mm lower value than that of the displacement-based AHOF in the same FWDB test. See Figure 17. The displacement-based AHOF may reduce the influence on the engine loading and this could be more beneficial in assessing structural interaction or geometry to enhance compatibility.

The Homogeneity Assessment proposed by TRL was computed to investigate the correlation between the two tests from a force distribution viewpoint [6]. This approach is developed to assess the homogeneity of forces in a vehicle foot print. Although the force distribution looks similar in the bar charts, the homogeneity assessment in the LCMDB test was twice as large as that in the FWDB test. See Figure 18. Haenchen et al. pointed out the issue of the impact alignment sensitivity of vehicles when the LCW data is used in compatibility assessments [7]. When concentrated loadings hit the junction between multiple load cells, those loadings are spread over several load cells. This may create a more homogeneous force distribution and may result in an advantageous assessment value. Because of the potential for the impact sensitivity of the load cell wall, repeatability tests will be necessary to check deviation in the homogeneity assessment of both FWDB tests and LCMDB tests.



	FWDB	LCMDB
Vc	23.3	52.4
Vr	10.5	23.4
Vcl	11.8	27.8
V	45.5	103.6

Vc : Cell Variance
Vr : Row Variance
Vcl : Column Variance



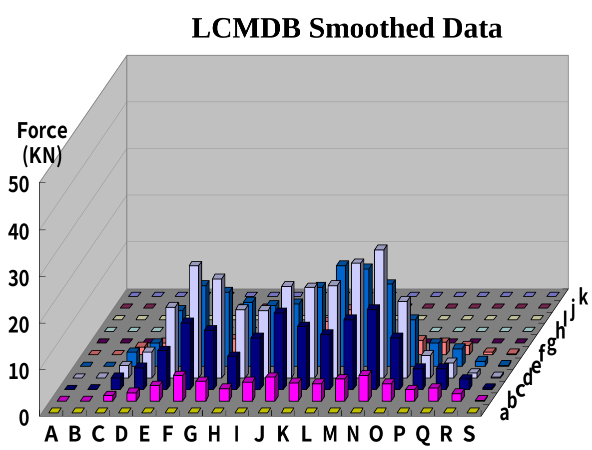


Figure 18. Comparison of homogeneity assessment

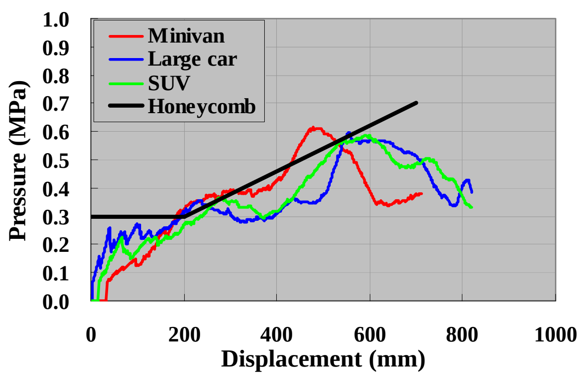
MDB-TO-VEHICLE OFFSET-FRONTAL CRASH TESTS

Generally speaking, when small vehicles are crashed into large vehicles, small vehicles experience harsher damage. Therefore, passenger compartment strength and deceleration levels are most significant for small vehicles in enhancing their self-protection performance. Apparently, providing survival space in collisions is a very important requirement for passenger compartments. Thus a passenger compartment strength test is needed to assess the passenger compartment strength to determine whether it is strong enough. An 80 km/h ODB test for passenger compartment strength has been proposed by TRL that uses a load cell wall (LCW) to assess the force generated by the vehicle [7]. However, the 80 km/h ODB test with the LCW is simply designed to measure the passenger compartment strength, and does not require instrumented dummies. What seems to be lacking is consideration of the injury mechanism during impact. Measurement of the passenger compartment strength alone may not be enough to assess injuries because injury levels are not only determined by maximum intrusion, but are also determined by the deceleration pulse. Naturally, instrumented dummies can detect the correct injuries.

An LCMDB test to assess self-protection performance may provide more realistic overload conditions compared to the 80 km/h ODB test. An offset-frontal LCMDB-to-vehicle test, with closing speed of 100 km, was conducted between the LCMDB and small vehicles with a mass ratio of about 2.0. Small vehicles could use this approach to help comply with passenger compartment strength requirements. In our previous study, nothing reproduced the deceleration pulses generated in vehicle-to-vehicle impacts better than the MDB test. As a consequence, the LCMDB-to-vehicle test could be a candidate procedure for assessing passenger compartment strength and the deceleration pulse.

Development of deformable barrier

In order to simulate a vehicle-to-vehicle impact, it is necessary for the DB to approximate the crush characteristics of actual vehicles. In this research, the use of the load cell data obtained from a FWDB test was used to make a custom-built DB that consisted of aluminum honeycomb elements. The force-displacement (F-D) characteristics in the FWDB test were transformed into the pressure-displacement (P-D) characteristics. Total barrier force was divided by the load cell area to generate a P-D curve. The P-D curve was the basis for assigning crush characteristics to the DB. The P-D characteristics of the DB for this study approximate the stiffness of large vehicles, which progressively increase in the pressure from 0.3 MPa to 0.7 MPa with 700 mm of crush depth to prevent bottoming out. See Figure 19.



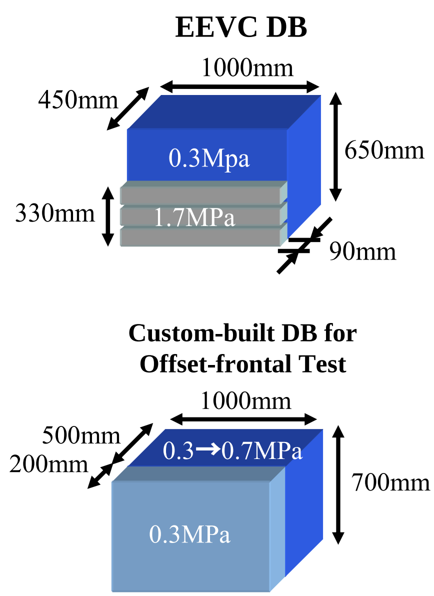


Figure 19. Pressure-Displacement Curve for LCMDB

LCMDB-to-vehicle offset-frontal impact

After the deformable barrier was developed, an LCMDB-to-vehicle testing was conducted to analyze load cell data. Figure 20 shows the layout of the load cells which are attached to the MDB. For an offset-frontal LCMDB impact, 64 load cells are arranged in an 8x8 matrix.

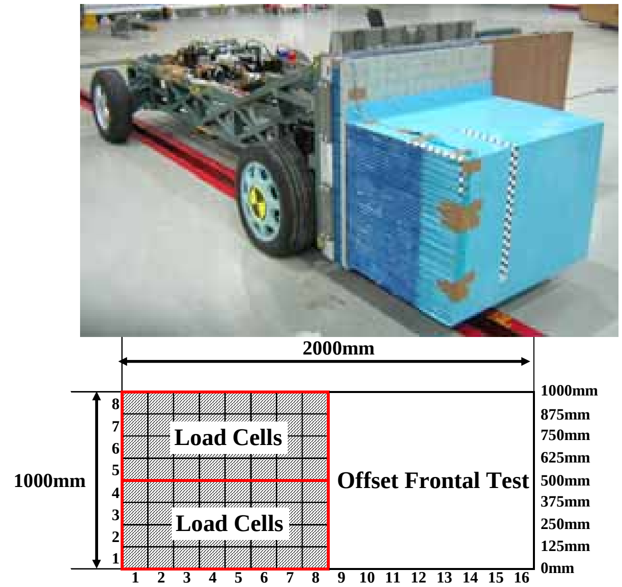


Figure 20. Load cell layout for offset frontal test

An LCMDB-to-vehicle impact was conducted to determine how well such an impact compared to vehicle-to-vehicle impact with a small car, to overload the passenger compartment and investigate its deformation resistance. The LCMDB weight was set to correspond to the modeled vehicle representing an SUV. The LCMDB was crashed into a compact sedan at 40% offset with closing speed at 100 km/h. Hybrid Ш 50th percentile male dummies were used to study the injury levels for the driver and passenger positions. See Figure 21.

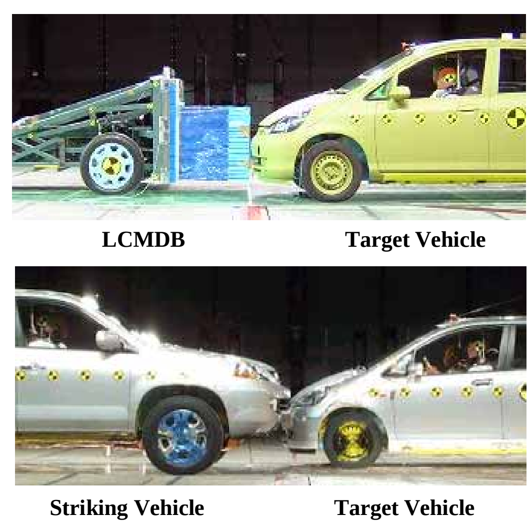


Figure 21. LCMDB-to-vehicle test configuration

Figure 22 shows the vehicle deformation and the dummy responses for the target vehicle. Fairly good fidelity was observed with regard to the vehicle deformation. Injury Assessment Reference Values (IARVs) was used to normalize the injury measurements. These reference values are defined in FMVSS 208. The result of the LCMDB-to-vehicle test shows that the injury measures were greater overall than those in the vehicle-to-vehicle test.

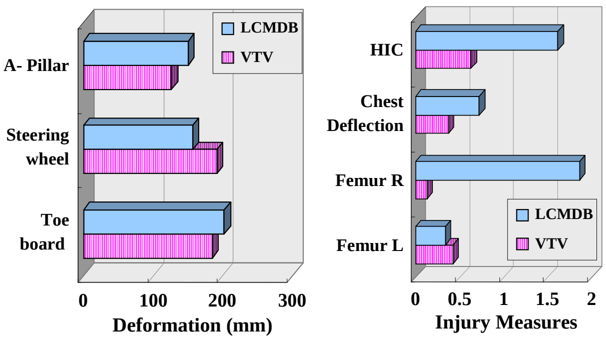


Figure 22. Comparison of vehicle deformation and injury measures for driver dummy

Barrier load cell data analysis

Figure 23 shows the contour graphs of the small vehicle which collided into the LCMDB in offset-frontal impact. From the contour graph, it was observed that the DB dispersed the crash forces over a wide area on the LCW. This is not an advantageous feature when considering load cell data analysis. Then, as can be seen in the contour graph at 30 ms, the load cells could not discriminate the stiff structure until the side member directly contacted the LCW. This could be a second issue of load cell data analysis with a deep DB.

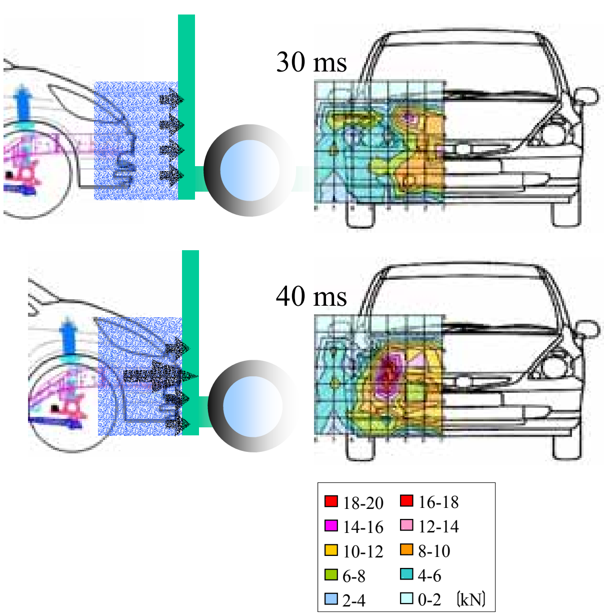


Figure 23. Load cell data analysis

Figure 24 compares the force-displacement characteristics of the target vehicle in the 64 km/h ODB test and in LCMDB test. The F-D curve in the LCMDB test was generally similar to those in the 64 km/h ODB test and obviously indicated an overload test for small vehicles. These F-D curves demonstrate that the LCMDB-to-vehicle test can simulate the ODB test and that the 80 km/h ODB test (over load test) can be replaced by the LCMDB test by choosing suitable test speeds.

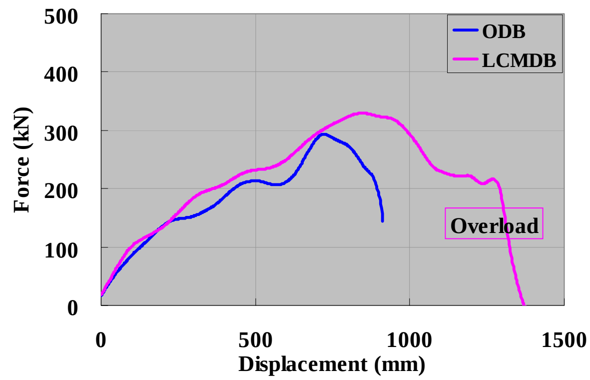


Figure 24. Comparison of force-displacement curves

Overall the load cell data analysis with deep DB may provide little information about what happens to the stiffness characteristics of the engine compartment. However, using an LCMDB test for assessing compartment strength can provide more realistic overload conditions, compared to the 80 km/h ODB test, on the basis that the LCMDB can represent large striking vehicles.

MDB-TO-VEHICLE OBLIQE-FRONTAL CRASH TESTS

Based on the analysis of National Automotive Sampling System (NASS) data, Ragland et al. reported that the frontal offset oblique crash test could be effective in enhancing vehicle safety performance in the real world [8, 9]. Enhancing the robustness of vehicle crashworthiness in relation to the impact angle may be quite important in real world accidents because almost all accidents have an impact angle, more or less. FMVSS 208 requires a fixed oblique barrier (FOB) test at 40km/h for occupant protection and FMVSS 301 requires the FOB test at 48km/h for fuel system integrity. However, fixed barrier tests only look at the crash condition between same weight vehicles. The MDB offers the ability to carry out various oblique offset tests. The MDB test method allows collisions of vehicles with different mass, which is unlikely to be confirmed by the fixed barrier test.

However, Sugimoto et al. reported the “bottoming out” issue of the DB in oblique-frontal MDB impact testing with an FMVSS 214 deformable face [10]. Therefore, an LCMDB with deeper DB was used to prevent bottoming out in this study, then vehicle and occupant kinematics were compared between the oblique-frontal LCMDB test and the vehicle-to-vehicle test.

A frontal 30 degrees oblique-frontal LCMDB-to-vehicle test was conducted according to the test configuration shown in Figure 25. At impact the left side corner of the target vehicle aligns with the center of the front of the striking LCMDB with a 100 km/h closing speed. A wider custom-build DB, which was twice as wide as that used in the offset-frontal test, was used for the oblique test. The load cell layout was the same as the full-frontal test (16 x 4). In this test, the target vehicle used a Hybrid Ш 50th percentile dummy which was restrained via seat belt in the driver position.

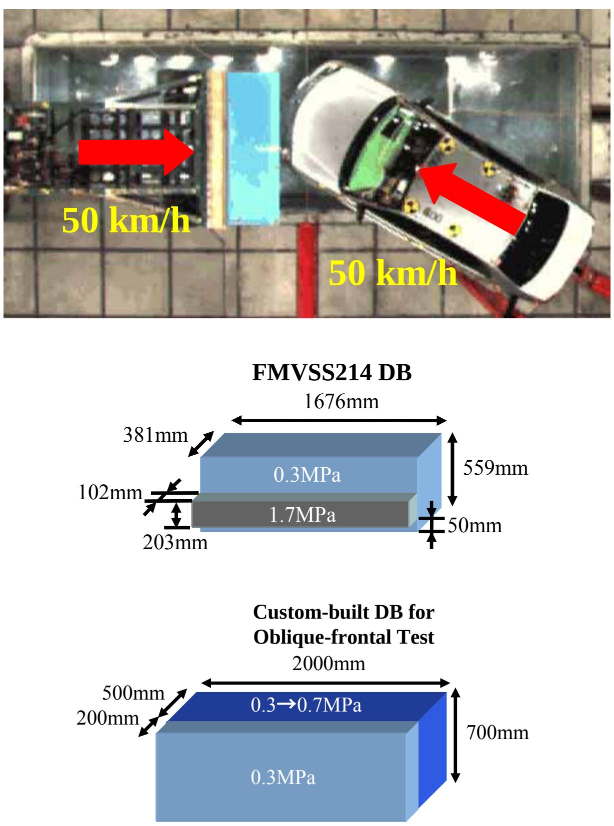


Figure 25. 30 degrees oblique-frontal LCMDB-to-vehicle test

The deformation levels and injury measures of the target vehicle were very similar for both the vehicle-to-vehicle (VTV) test and LCMDB-to-vehicle in comparison with the fixed oblique barrier test. See Figure 26.

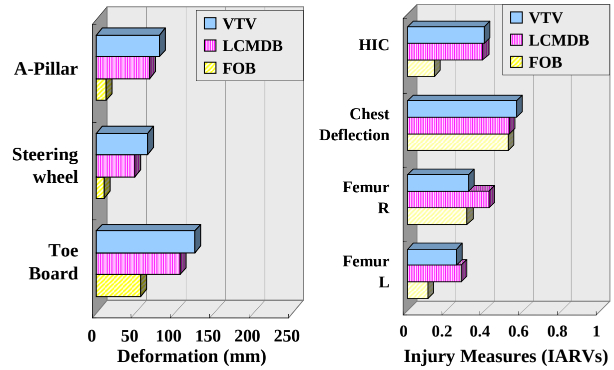


Figure 26. Comparison of vehicle deformations and injury measures for driver dummy

The primary difference in these data is seen in the time to rise from the initiation of the event. The vehicle deceleration in the LCMDB test begins to rise earlier than that in the vehicle-to-vehicle test. The deceleration pulse in the LCMDB test also shows a substantially shorter duration time. This may be caused by the lack of a bumper element for the LCMDB. See Figure 27.

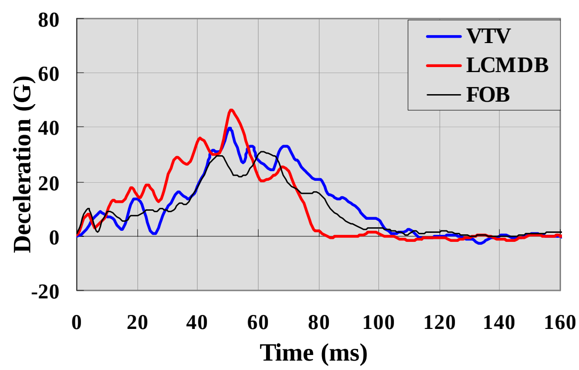


Figure 27. Comparison of vehicle deceleration pulses

The head responses of the dummy in the LCMDB test also rise earlier than in the vehicle-to-vehicle test, but are otherwise similar in terms of profile and magnitude. See Figure 28-30.

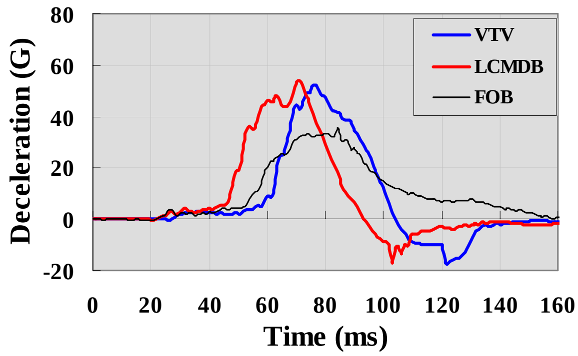


Figure 28. Comparison of Head-X deceleration pulses

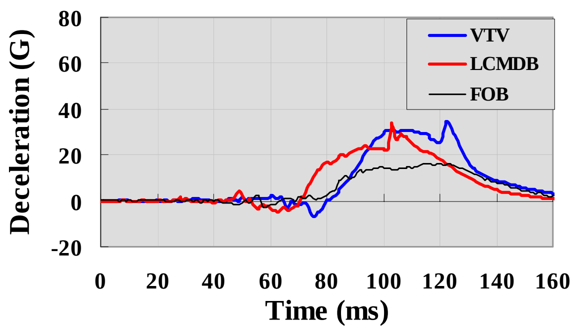


Figure 29. Comparison of Head-Y deceleration pulses

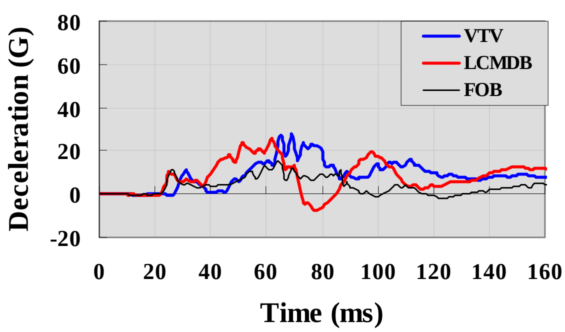


Figure 30. Comparison of Head-Z deceleration pulses

High speed video analysis was used to confirm kinematics of the events which are shown in Figure 31. The primary focus of this paper is on the vehicle dynamic response and occupant kinematics in the oblique-frontal LCMDB test configuration. As can be seen in Figure 31, the kinematics responses for these tests were very similar, both for the vehicle-to-vehicle test and the LCMDB-to-vehicle test respectably.

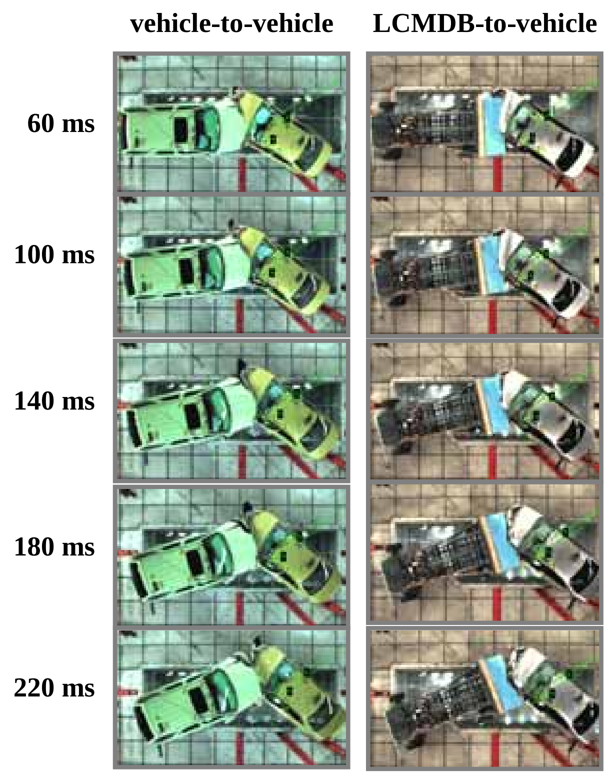


Figure 31. Comparison of vehicle kinematics responses

The dynamic movements of the right and left side A-pillar of the target vehicles were compared in figure 32. The trace in the LCMDB-to-vehicle test was similar to that in the vehicle-to-vehicle test, while the trace in the fixed oblique barrier (FOB) test was different from that of the vehicle-to-vehicle test in terms of the rebound movement of the target vehicle. This is because the LCMDB test can produce a mass effect in the vehicle dynamic responses.

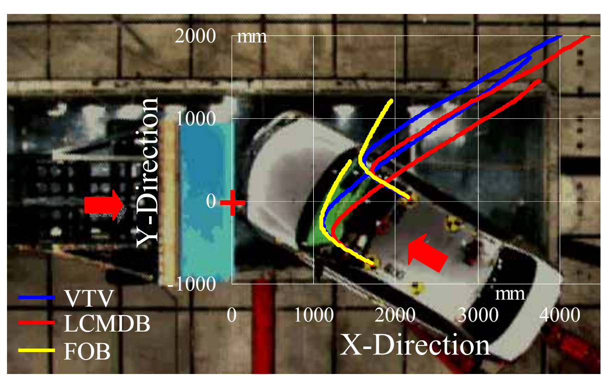


Figure 32. Comparison of A-Pillar traces (X, Y direction for LCMDB)

Since vehicle dynamic responses in the LCMDB test were similar to those in the vehicle-to-vehicle test, the driver dummy head kinematics in the LCMDB test was also similar to those in the vehicle-to-vehicle test. The rotational movement of the dummy head around the air bag was well simulated by the LCMDB testing. See Figure 33.

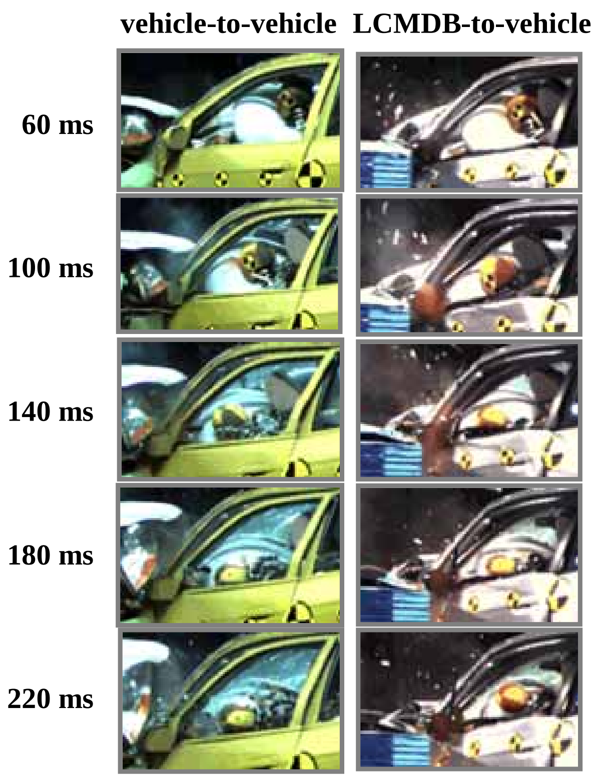


Figure 33. Comparison of dummy head kinematical responses

When comparing the F-D characteristics between the oblique-frontal LCMDB test and 64 km/h ODB test, the F-D curve in the oblique-frontal LCMDB test indicated over all a lower force level than that in the 64 km/h ODB test. The F-D curve in the early stages of the impact for the oblique-frontal LCMDB test indicated that energy absorption in the engine compartment of the target vehicle may be decreased by the oblique impact. Simultaneously total impact energy may also be decreased by the rotational movement of the vehicle. See Figure 34.

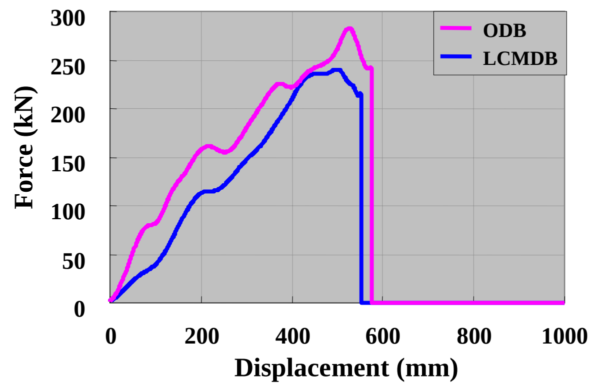


Figure 34. Comparison of force-displacement characteristics

Figure 35 shows the body deformation on the target vehicle in the LCMDB tests. The reason for the lower F-D curve in the LCMDB test may be because the oblique LCMDB impact applied lateral forces to the engine compartment and the side member of the target vehicle was unable to sufficiently to absorb the impact energy. It was observed for the target vehicle that the obviously lower deformation levels were seen at the front-end of the side member. An oblique offset LCMDB test may assess the robustness of impact energy absorption capability in engine compartments of vehicles against impact angle; hence the oblique offset LCMDB could be used to assess self-protection performance in the oblique impact.

Figure 35. Body deformation of the target vehicle

DISCUSSION

Testing of compatibility should evaluate the characteristics that can be changed to enhance compatibility in frontal impacts. According to a report published by the IHRA, structural interaction, frontal stiffness, passenger compartment strength, and deceleration pulse are important issues for frontal impact compatibility [11]. At present, vehicle fleets differ in mass, stiffness, geometry and many other design parameters in countries, and traffic environments also differ according to the country. The MDB test method is considered a research item for the longer term in the IHRA ; however, MDB-to-vehicle testing provides more flexibility in simulating vehicle-to-vehicle crashes, hence the MDB test would offer the best overall coverage of real world accidents.

CONCLUSION

This paper presented findings on LCMDB-to-vehicle crash testing for consideration in future research into frontal impact compatibility. In this study, the response characteristics of the target vehicles were compared to those in the fixed barrier and LCMDB crash test modes.

In full-frontal energy equivalent LCMDB tests with the shallow DB (2000 mm x 750 mm x 300 mm), while the peak LCW data values measured by the LCMDB test are slightly different from those measured by FWDB testing, the profiles of the data producing the results are comparable. The full-frontal LCMDB test could use the compatibility metrics of fixed barrier tests to assess the interaction characteristics and the stiffness of vehicles (sometimes referred to as the "aggressivity" of vehicles). Repeatability tests will be required for full-frontal LCMDB tests to confirm the stability of the compatibility metrics between tests.

In offset-frontal LCMDB tests with the custom-built DB (1000 mm x 700 mm x 700 mm), using heavy LCMDBs representing large striking vehicles may produce more realistic overload conditions, which simulate the body deformation and deceleration observed in actual vehicle-to-vehicle impacts, to evaluate the passenger compartment strength for small vehicles. Hence an LCMDB collinear offset impact could evaluate self-protection performance for small vehicles.

In oblique-frontal LCMDB tests with the custom-built DB (2000 mm x 700 mm x 700 mm), the results of the 30-degree oblique offset LCMDB test clearly show that the response characteristics of both the target vehicle and the occupant in the LCMDB-to-vehicle test are similar to those in the vehicle-to-vehicle test. Since an oblique-frontal LCMDB test may assess the energy absorption capability in the engine compartment of vehicles, the oblique-frontal LCMDB test may evaluate robustness of self-protection performance of vehicles against impact angles.

Overall, the LCMDB could be used as an advanced assessment device for use in frontal compatibility testing. Compared to fixed barrier tests, LCMDB testing has improved the fidelity of vehicle-to-vehicle impact in terms of the mass ratio to be taken into account. The LCMDB test method calls for further investigation, however, the LCMDB testing might have significant advantages in comparison with fixed barrier tests.

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