RESEARCH ON VEHICLE COMPATIBILITY IN JAPAN

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ABSTRACT

Test procedures to assess vehicle compatibility were investigated based on a series of crash tests. This paper summarizes the research reported by Japan to the IHRA Compatibility Working Group.

Based on full frontal impact tests, the force distributions to evaluate homogeneity were examined by a crash test of a large car as well as JNCAP tests. The AHOF has a correlation with longitudinal member heights and vehicle mass.

A PDB test was carried out using a large car, and the deformation of the barrier was a good indicator for structural interactions. The shear connections of the front structures could be evaluated compared with ODB and full frontal tests.

The results of three overload tests were examined. The maximum force and end of crash force in overload tests has a correlation with those in car-to-car crash tests, which indicated the effectiveness of this test method.

INTRODUCTION

Compatibility is defined as the ability to protect not only the occupants, but also other road users as well. Analyses of global accident data of car-to-car collisions from various countries have indicated that there are vehicles with low compatibility, such as cars with poor self-protection and cars with high aggressivity with respect to other cars. The aggressivity of sport utility vehicles (SUV) has become an issue in the United States and Australia, as has the self-protection of small cars in Europe. In Japan as well, vehicle sizes vary widely, and compatibility is considered an important problem. It is therefore necessary to evaluate and improve compatibility performance based on crash tests.

Test procedures for evaluating and improving the compatibility of passenger cars are currently under discussion in the International Harmonized Research Activities (IHRA) Compatibility Working Group [1]. Japan considers the activities of the IHRA to be a significant way to that will inform future legislation and regulation, and has conducted research with the aim of making an active contribution to these activities.

This paper summarizes the results of crash tests that Japan has conducted and reported to the IHRA Compatibility Working Group from 2001 to 2003. The test series includes full frontal rigid barrier tests, progressive deformable barrier (PDB) tests, offset deformable (ODB) tests and overload tests. Each test evaluates the different features of compatibility performance. Structural interactions are evaluated by full frontal test and PDB test, energy control are by ODB tests and compartment strength by overload tests. Criteria of each test were examined as a means to improve compatibility.

FULL FRONTAL IMPACT TEST

In full frontal tests, the barrier force distributions are measured from load cells, and structure alignment and homogeneity, which are effective for structural interactions, are evaluated. At present, Japan has a full rigid barrier crash requirement in the regulation, which will be useful if the compatibility can be evaluated in this test. In the present study, force distributions in full rigid barrier tests were examined in a test using a large car and JNCAP (Japan New Car Assessment Program) tests.

Crash Test

A large car (Toyota Crown, TA-JZS171-AEPSH, curb mass 1545 kg) was impacted against a rigid barrier with high resolution load cells. The size of the load cell is 125 mm x 125 mm, and a wood plate is attached on each load cell (Figure 1). The impact velocity of the car was 55 km/h. The structure of this car model consists of longitudinal members, bumper beam and shotguns without subframe.

Figure 2 presents a side view of the impacted car. The front structures deformed flat. Figure 3 shows the time histories of barrier, mechanical, structural force and the sum of the mechanical and structural forces. The mechanical and structural forces are calculated based on the acceleration of the engine and the side sill, respectively. The barrier force coincides well with the sum of the mechanical and structural forces. The barrier force has a peak at 40 ms, at which the mechanical force reaches maximum.

Figure 4 shows the barrier force distributions obtained by load cells. The bumper beam can be seen in the first 5 ms. After that, the force concentrations by the longitudinal members emerged. Forces from shotgun are shown at 25 ms, those of the engine at 30 ms, and those of the tire at 35 ms. The footprint by the longitudinal structures can be easily seen, however the lateral structures can be seen only in the limited time. Judging from the footprint, the effect of engine impact was large. The forces of longitudinal structures emerged individually, and the shear connections between them may be difficult to evaluate directly.

The center of force (COF) and average height of force (AHOF) were obtained from the force distributions. The COF is the height weighted by the force in each time [2]. AHOF is calculated based on the COF weighted by the total barrier force over impact duration. Figure 5 shows the AHOF and COF. After impact, the COF increases because the force distributes from the bumper area to the upper area due to the engine and shotgun impact. COF has a peak around 30 ms. After 60 ms, the car separated from its upper part of the front end, then the COF decreased. AHOF is 464 mm, and this value is almost the same as COF when the impact force is largest at around 40 ms.

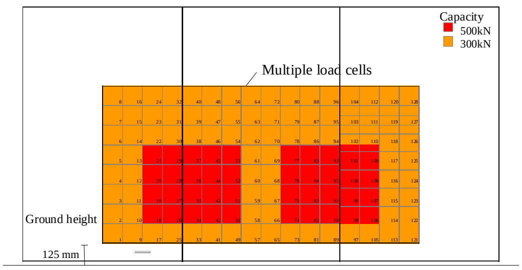


Figure 1. High resolution load cells

Figure 2. Car deformation in full rigid barrier crash tests.

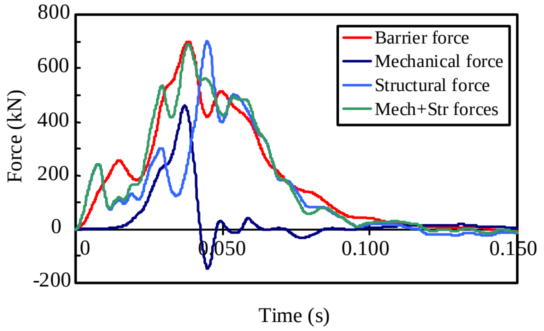


Figure 3. Force-time histories in a full rigid barrier crash test.

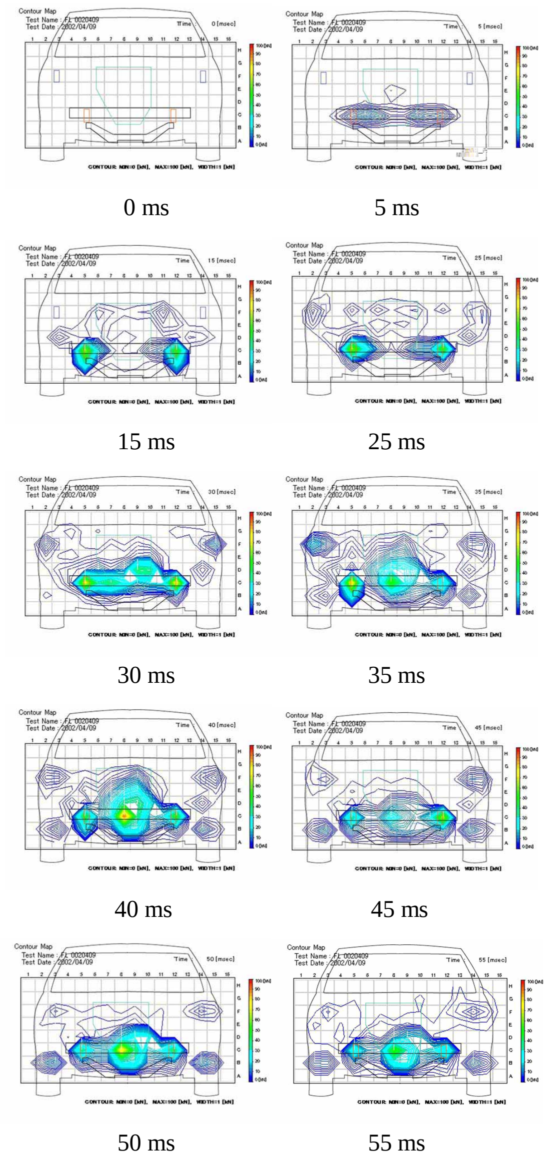


Figure 4. Barrier force distributions in full rigid barrier crash test (55 km/h).

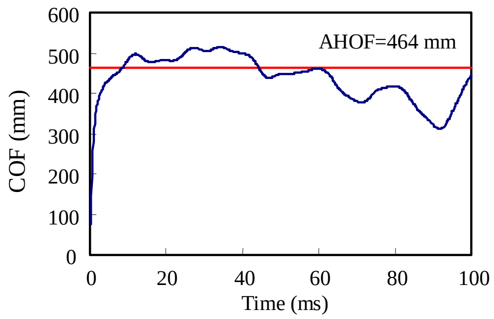


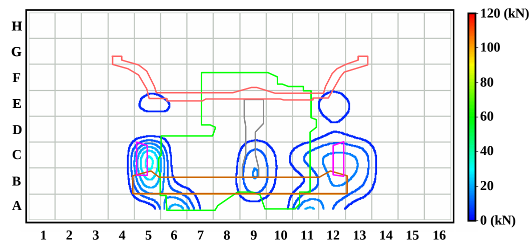
Figure 5. COF and AHOF in a full rigid barrier crash test.

JNCAP Test Results

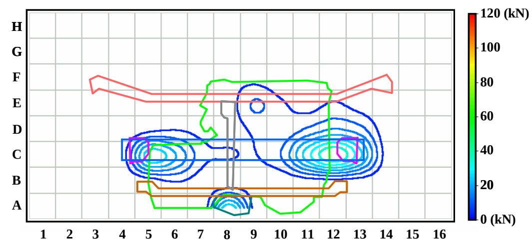
In 2003 JNCAP, the high resolution load cells were attached on the rigid barrier to measure the barrier force distributions in full frontal impact tests. An impact velocity was 55 km/h. Totally 22 cars were tested, which consisted of 6 minicars, 6 small cars, 4 midsize cars, 5 MPVs (multi-purpose vehicles) and 1 SUV (sports utility vehicle). The geometries of the front structures such as longitudinal members, bumper beam, subframe and engine were measured, and the relation between these locations and force distributions were examined.

<u>**Vehicle structures and force distributions**</u> The force distributions of cars with different structures such as a bumper beam, lower cross member (radiator support) and subframe were examined. Figure 6 shows force distributions with typical structures before the total force reached maximum. For the minicar without a bumper beam, the forces concentrated around longitudinal members. For the medium car with bumper beam and lower cross member (without subframe), the forces extended from longitudinal members to the center of bumper beam. There was also force concentration from the center of the lower cross member. However, the attachment locations of the lower cross member cannot be seen because these members are not so stiff in the longitudinal direction. It is considered that the lower cross members will be difficult to identify in the force distribution when these members are not connected rigidly. For the SUV, which also has a subframe, the forces distributed more widely around subframe attachment locations. These results demonstrate that, in evaluating the structural force, the force distributions in full rigid barrier crash tests are useful.

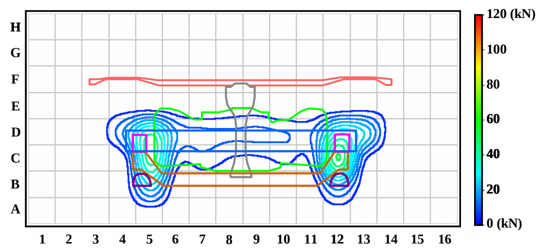
<u>**AHOF by vehicle model**</u> The AHOF of each vehicle model in JNCAP are shown in Figure 7. The AHOF averaged for all tested vehicles is 443 mm. The AHOF averaged for each car size is 415 mm for minicars, 442 mm for small cars, 433 mm for medium cars, 473 mm for MPVs and 488 mm for SUV. The AHOF is higher for MPV and SUV, though there is a variation among vehicle models.



(a) Minicar without bumper beam (10 ms)



(b) Medium car with bumper beam and lower cross member (30 ms)



(c) SUV with bumper beam, lower cross member and subframe

Figure 6. Typical force distributions for vehicles with various structures.

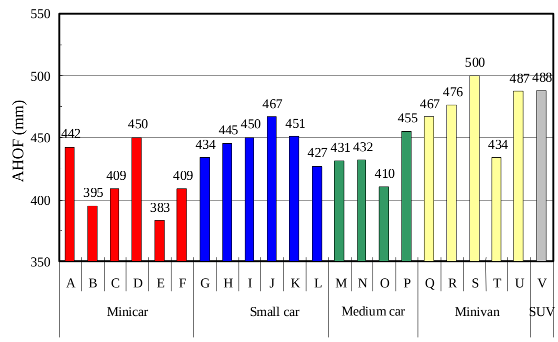


Figure 7. AHOF in JNCAP.

<u>**AHOF and vehicle parameters**</u> The vehicle parameters examined were vehicle mass, the heights of the longitudinal member, bumper, lower cross member, and engine. In these parameters, the vehicle mass, longitudinal member height, engine top height and bumper top height have a correlation with AHOF (Figures 8, 9 and 10).

Figure 11 presents the force distribution of MPV which showed the highest AHOF (500 mm) in the JNCAP 2003 test. There are force concentrations from longitudinal members and engine. In this way, the heights of longitudinal member and engine top can affect the AHOF.

The AHOF in the tests was formulated by the vehicle mass and longitudinal member height using a linear expression based on the least-squares method. Using two parameters, the AHOF can be expressed with a relatively higher coefficient of correlation than using only vehicle mass. This result indicates that not only vehicle mass but also longitudinal member height affects the AHOF.

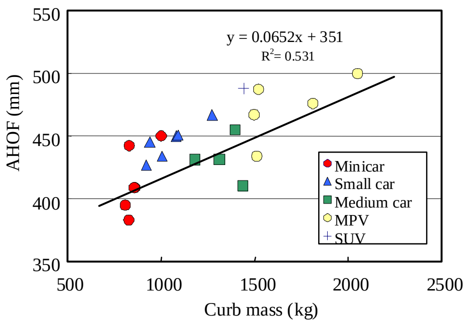


Figure 8. Vehicle mass and AHOF.

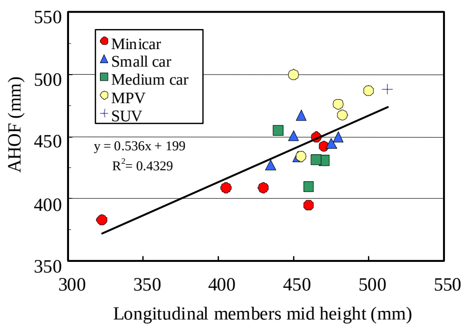


Figure 9. AHOF and longitudinal member heights (midpoint between top and bottom of longitudinal member front end).

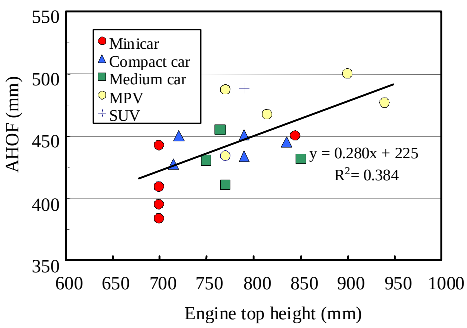


Figure 10. AHOF and engine top height.

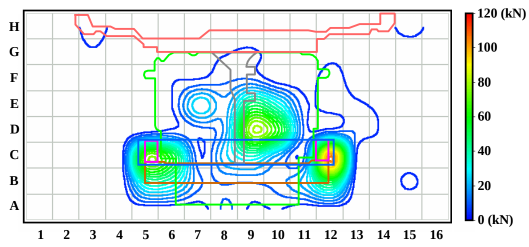


Figure 11. Force distributions at the time of maximum force (37.8 ms) of MPV which had the highest AHOF in JNCAP 2003.

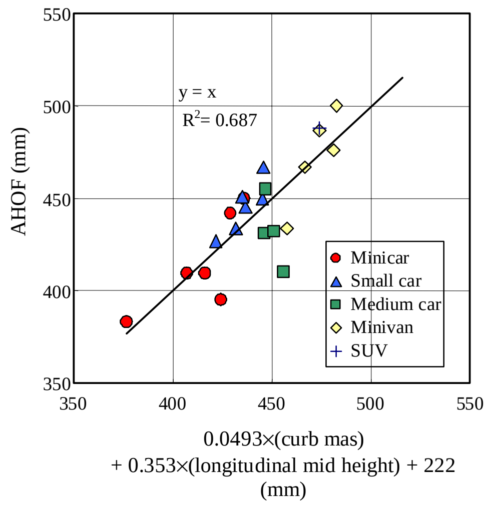
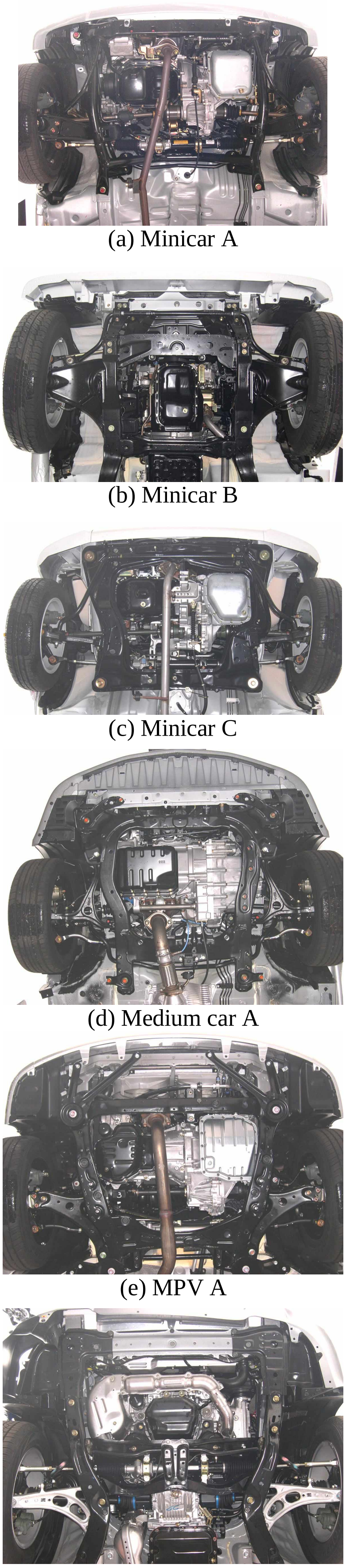


Figure 12. AHOF formulated by vehicle curb mass and longitudinal member mid height.

Subframe footprint A subframe can be one solution to provide a lower load path which constitutes a multiple load path, and can prevent override of the vehicle in a car-to-car crash. In vehicles tested in JNCAP 2003, 6 cars had a subframe, and the force distributions by that subframe and its effect on CV (coefficient of variation) were examined.

The distance of the subframe from the car front end is 290 mm for minicar B, 330 mm for MPV A, 410 mm for medium car A. For the minicar A, C and SUV, the subframe is just in front of the car and connected with the lower cross member.

Figure 14 presents the force distributions at the maximum force. The force around subframe attachment can be seen. However, lateral traces of the force due to the subframe are difficult to identify. Thus, it may be difficult to identify the subframe itself from the force distribution. However, the subframe can make the force distribution in a lower area more homogenous. Thus, proper criteria will be necessary to evaluate the force distribution by these lower structures.



(a) Minicar A

(b) Minicar B

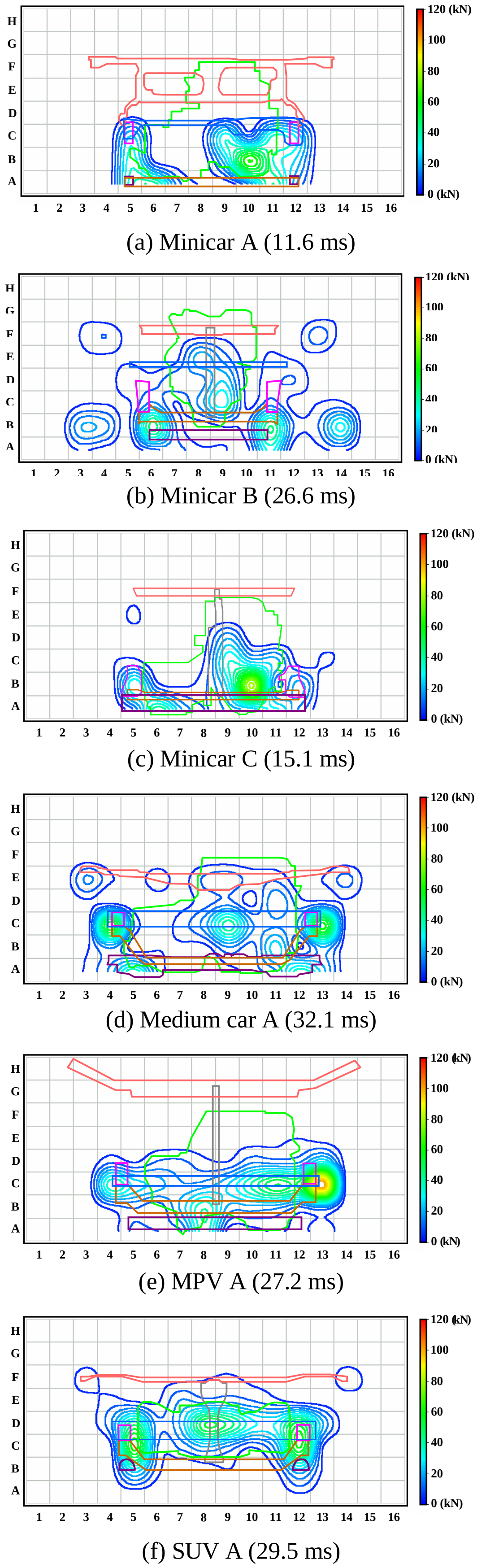
(c) Minicar C

(d) Medium car A

(e) MPV A

(f) SUV A

Figure 13. Subframe.



(a) Minicar A (11.6 ms)

(b) Minicar B (26.6 ms)

(c) Minicar C (15.1 ms)

(d) Medium car A (32.1 ms)

(e) MPV A (27.2 ms)

(f) SUV A (29.5 ms)

Figure 14. The force distributions at the time of maximum force for vehicles with subframes.

The coefficient of variation (CV) is one of the parameters used to evaluate the structural homogeneity [3]. In the first phase of a crash, the CV is large because only limited structures such as longitudinal members contact the barrier. The CV decreases with time and becomes almost constant at the time of the engine impact. However, at that time, the force from the engine is so large that the effect of the subframe on the force distribution can be small. Thus the CV at the time before the engine force emerges was examined. When difficult to identify this time, the time when the total barrier force reached half of the peak force due to engine impact was used. Figure 15 shows the CV with and without a subframe. Cars with a subframe have smaller CV than those without one. Medium car A had a large CV, possibly because the subframe is located behind the car front end, and the footprint of the subframe did not emerge in the first phase of crash (Figure 13). Therefore, the force of the subframe may be evaluated using some criteria like CV before engine impact.

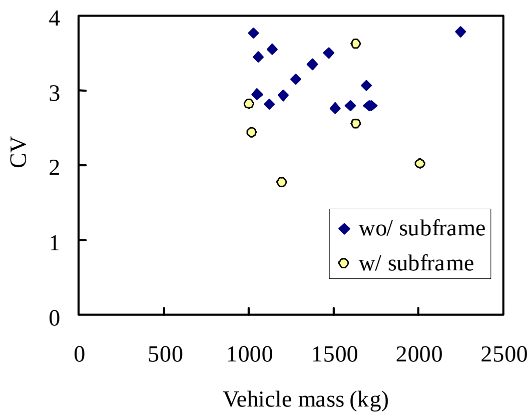


Figure 15. CV before engine impact.

PROGRESSIVE DEFORMABLE BARRIER TEST

PDB tests are the offset impact tests which have been proposed by Renault [4]. PDB is a barrier which has stiffness distributions in the longitudinal and vertical directions based on the stiffness of a small car. The impact velocity is 60 km/h. The aggressivity of the car can be evaluated by the deformation of the barrier. In this research a PDB test was carried out using the Toyota Crown (TA-JZS171-AEPSH, curb mass 1547 kg). Though usually no dummies are seated in the PDB test, a driver dummy was used in this research, and the injury criteria were also compared with those in an ODB test.

Deformation of the car and honeycomb are shown in Figure 16. In the PDB test, the shear deformation occurs in a longitudinal and vertical direction, similar to the case of a car-to-car crash test. The deformation modes of the longitudinal member and shotgun were different from those in full rigid barrier crash test (see also Figure 2). The deformation of the PDB was relatively uniform but the trace of the bumper beam can be seen, which indicated the bumper beam effectiveness of this car in offset impacts. Thus, based on the deformation of the honeycomb, lateral members such as the bumper beam, lower cross member and subframe can be evaluated by the PDB test more directly than full rigid barrier impact tests based on the PDB deformation. From a high-speed video, the effect of car rotation around z-axis in a final stage of impact on the barrier deformation was not so large because the barrier did not bottom out.

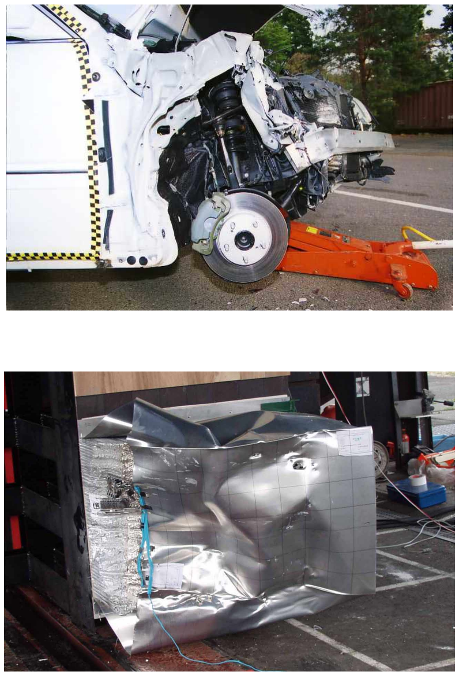


Figure 16. Car and barrier deformation in a PDB test (60 km/h).

The force distribution with time is shown in Figure 17. Although the footprint from the engine can be seen, the forces were dispersed by the thickness of the PDB honeycomb, and the footprint of the front structures was difficult to identify. Due to the honeycomb shear stiffness, the barrier force appears even outside the car exterior. Thus, it is difficult to assess the force distributions based on the loadcells behind the barrier.

COFs of the PDB test and full rigid barrier are shown in Figure 18. The COF is similar between these tests before 40 ms, and the COF of the PDB test is smaller than full rigid barrier test during engine impact into the barrier from 40 to 100 ms.

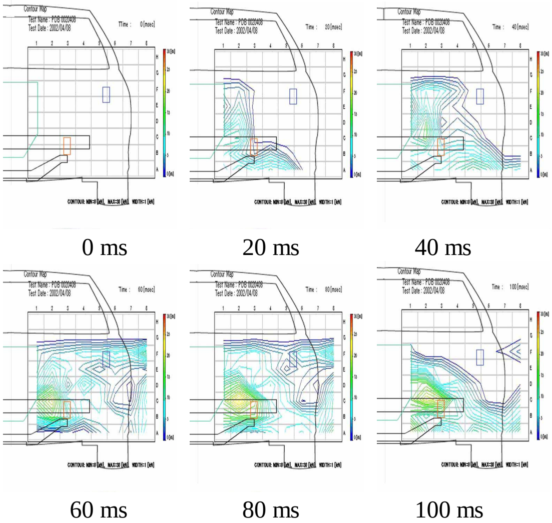


Figure 17. Barrier force distributions in PDB test.

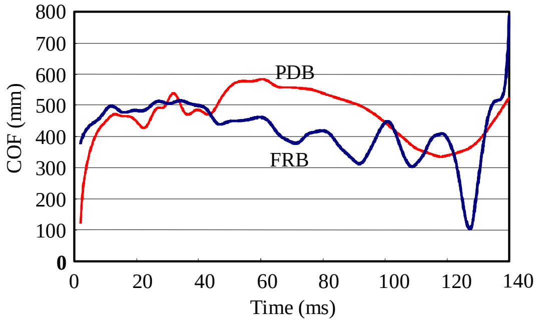


Figure 18. Center of force determined from PDB and full frontal rigid barrier crash test.

Comparison between PDB and ODB Test

The deformation and acceleration were compared in the PDB (60 km/h) and ODB 64 km/h tests (JNCAP). The overlap ratio of the car in the ODB test is 40%. In PDB tests, the overlap of the car front is 750 mm and the overlap ratio is almost 40% for the tested car. Since the impact velocities are different in these tests, the test results can not be compared directly.

Figure 19 presents the deformation of the car and the ECE R94 honeycomb. Because of bottoming out of honeycomb, the car front deformation became more flat in the ODB test. In the PDB test, the front edge of the fender deformed rearward relative to the bumper, where shear connections between them can generate, which may be similar to car-to-car crashes. In the ODB test, the barrier bottomed out, and the honeycomb bumper separated from the barrier, thus the deformation of the barrier became complicated. On the other hand, the PDB honeycomb had a continual deformation, which made easier for deformation measurement.

Acceleration-time histories in the PDB and ODB test are shown in Figure 20. The acceleration of the compartment is similar between these two tests. The engine accelerations are similar in the initial stage in both tests, and after 60 ms the engine acceleration in the ODB test is higher than the PDB test because of the bottoming-out of the ECE R94 honeycomb.

The injury criteria of driver dummy in the PDB test were HIC 300, chest acceleration 380 m/s^2, chest deflection 30.6 mm, femur force 0.75 kN (right), 1.27 kN (left) and tibia index 0.35 (right lower) and 0.46 (left lower). In the ODB test, HIC was 269, chest acceleration 421 m/s^2, chest deflection 34.8 mm, femur force 2.46 kN (right), 2.41 kN (left), tibia index 0.85 (right lower), and 0.29 (left lower). The injury criteria of the driver were more severe for ODB 64 km/h test due to the high acceleration and large deformation of the car, particularly the injury criteria for the lower extremities.

The acceleration and deformation show the possibilities that the ODB test may be carried out with PDB instead of ECE R94 honeycomb. But a high impact velocity can lose the benefit of the PDB barrier because the bottoming-out of the PDB honeycomb can occur.

Figure 19. Car and honeycomb deformation in a 64 km/h ODB test.

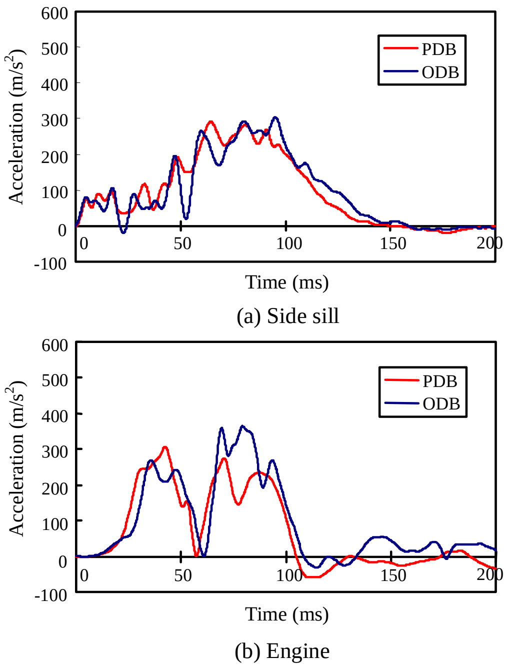


Figure 20. Acceleration-time histories in PDB (60 km/h) and ODB (64 km/h) test.

ODB TEST

In the ODB test, the force-deformation characteristics and maximum force will be the important criteria to evaluate the compatibility performance. The barrier force has the potential to evaluate vehicle stiffness, and corresponds to the crash force of the interface in car-to-car crashes. The maximum barrier forces were determined form JNCAP offset impact test data (2001-2002). Figure 21 shows the linear relation between vehicle mass and the maximum barrier force which can be aggressivity metric. Some MPVs and medium cars have high force levels above 400 kN. An upper limit will be necessary for the maximum barrier force to control aggressivity.

Stiffness distributions were also examined based on the barrier force and the honeycomb deformation. In the JNCAP offset impact tests, only 6 load cells are attached behind the honeycomb. Thus in the present research, the barrier forces from the upper and lower part were examined. Figure 22 shows the barrier force-time histories averaged for the vehicle class. In minicars and small cars, the upper force tended to be smaller than the lower force, possibly because these cars did not have effective upper load paths.

The barrier force-time histories and honeycomb deformation of car A and car B, both of which are small cars with a similar mass, are presented in Figure 23 and Figure 24. The maximum force was about 250 kN for both car A and B. In car A, the upper and lower forces were balanced, and the honeycomb deformation was uniform. In car B, the upper force was smaller than the lower force, and the lower part of the honeycomb bottomed-out while the upper part showed no large deformation. These results indicated that the car A stiffness distributions in the upper and lower parts were homogeneous, and the upper part had a resistant force which could prevent underride in a collision with various vehicles.

These results demonstrate that the maximum force or the stiffness distributions in the upper and lower area vary significantly in vehicle models. The barrier deformation in PDB tests or force distributions in full frontal tests can clarify the stiffness distributions more clearly. However, the ODB tests can reflect the actual condition of vehicle stiffness distributions.

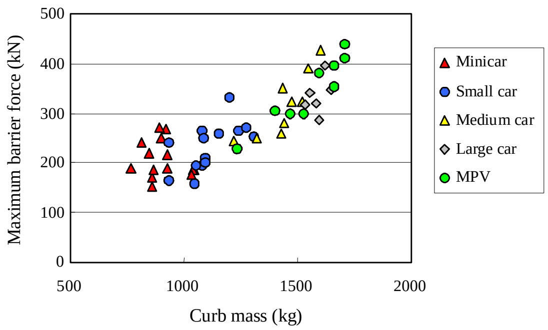


Figure 21. Maximum barrier force and vehicle mass in ODB 64 km/h (JNCAP 2001-2002).

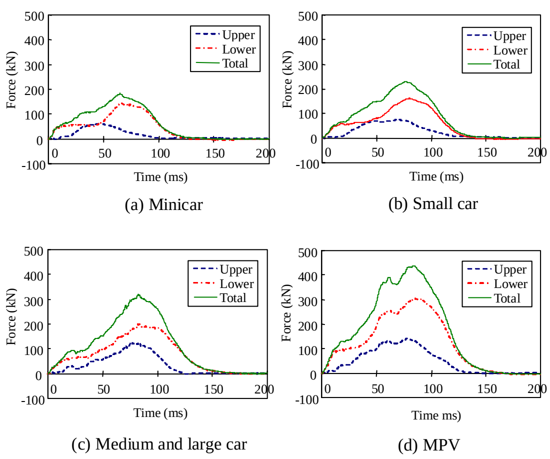


Figure 22. Average barrier force-time histories in offset frontal impact tests by car class (JNCAP 2001).

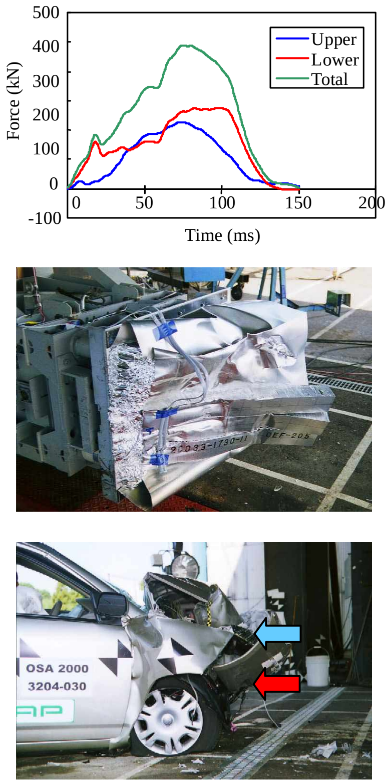


Figure 23. Barrier force-time histories and barrier deformation of car model A in ODB test (JNCAP).

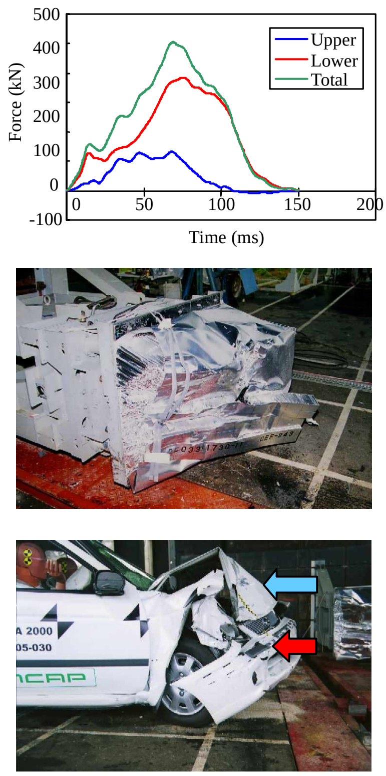


Figure 24. Barrier force-time histories and barrier deformation of car model B in ODB test (JNCAP).

OVERLOAD TESTS

Test Method

An overload test is a high-velocity ODB test causing a large intrusion into the compartment. In the present research, overload tests were conducted using the Move, Wagon R and Civic models. An impact velocity of 80 km/h with 40% overlap on the ECE R94 barrier was used to collapse the passenger compartment completely. A barrier force and an average acceleration of both B pillars were used to measure the passenger compartment strength. The force and deformation were compared with crash tests into the Toyota Crown (Move x Crown, Wagon R x Crown, Civic x Crown).

Table 1 Test matrix in overload tests

Car model	Model year	Velocity (km/h)	Curb mass (kg)	Test mass (kg)	Overlap ratio	Remarks
Daihatsu Move (minicar)	2000	80.0	845	845	40%	Without dummies
Suzuki Wagon R (minicar)	2002	80.3	822	822	40%	Without dummies
Honda Civic (Small car)	1998	80.0	1094	1095	40%	Without dummies

Force-Time Histories

Figure 25 shows force-time histories of the barrier force, mechanical force and structural force. The barrier force reached its maximum when the mechanical force peaked due to the engine impact against the barrier. This maximum barrier force was almost the same as the sum of structural and engine forces. At this time, the engine bottomed out the barrier, and at the same time contacted the fire wall, presumably beginning the intrusion into the passenger compartment.

After the engine stopped, the floor and side sill began to deform and buckle, which resulted in the collapse of the passenger compartment. At this final stage of the passenger compartment collapse, the deformation became large, especially when the end of the crash force obtained from the barrier was low, as with the Civic. The Wagon R and Civic indicated the low end of the crash force in the overload test, though the Move maintained a high end of crash force. In a crash into the Crown, the passenger compartment intrusion became large for the Wagon R and the Civic, both of which had the low end of crash force in the overload test.

The acceleration curve of the Civic shows vibration. With the passenger compartment collapse and consequent destabilization of the Civic, the acceleration curves measured at the right and left sills and rear cross member showed an observable deviation. The Move accelerations at these locations are similar, which indicates the stability of the passenger compartment of this car.

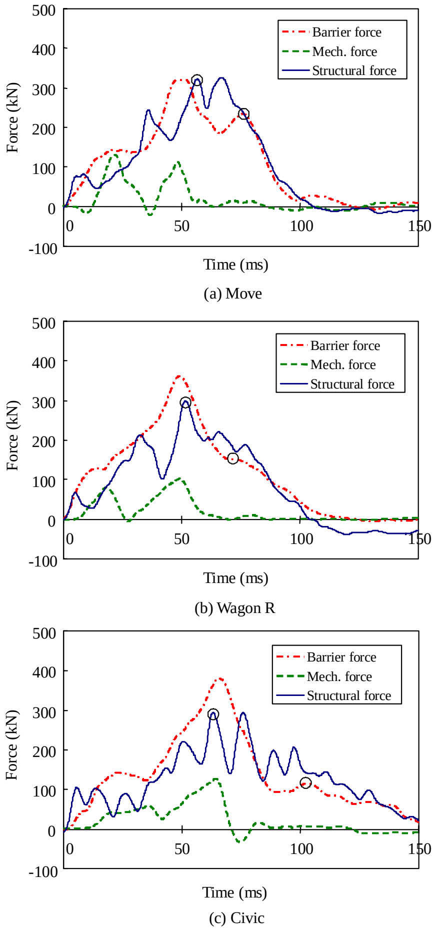


Figure 25. Force-time histories in overload tests.

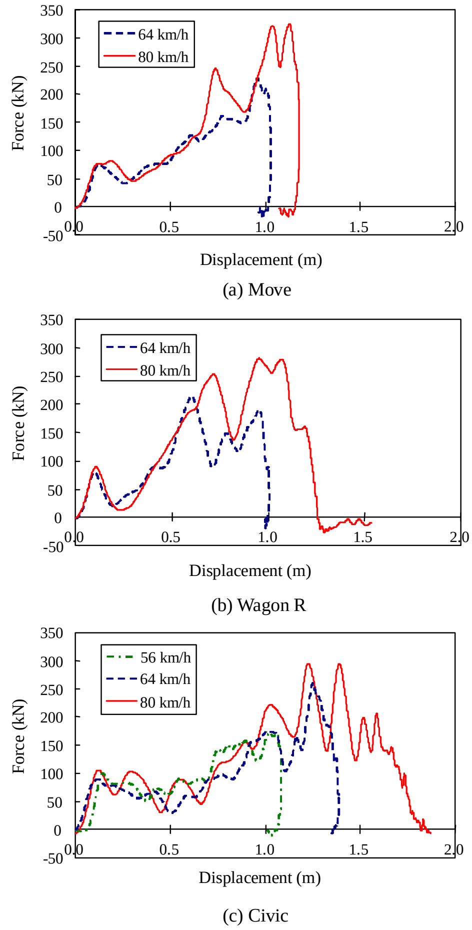


Figure 26. Force-displacement curves in ODB tests according to impact velocities.

Force-Displacement Characteristics by Impact Velocities

The structural force curves with displacement are shown in Figure 26 for the Move, Wagon R and Civic, respectively, according to impact velocity. Since the structural force-displacement characteristics described a similar curve, regardless of velocity, the car deformation mode at 80 km/h may be considered to match those at lower velocities.

The Move maximum force was 330 kN in the overload test, which was higher than that in the ODB test (220 kN). Thus, whereas the force of the Move and Wagon R did not reach their passenger compartment strength at 64 km/h ODB test, the overload test could determine the actual passenger compartment strength. The maximum forces of the Civic in the overload test and in the 64 km/h ODB test were very similar at around 250-280 kN. However, the low end of crash force could be detected from the overload test. Although a large intrusion into the passenger compartment was found in the ODB 64 km/h tests of the Wagon R and Civic, the 64 km/h ODB test might be insufficient to evaluate the threshold of the criteria for passenger compartment strength.

Evaluation of Passenger Compartment Strength

Based on the force-time histories, two criteria can be considered in evaluating the strength of the passenger compartment. The first is 'the maximum force level' which basically makes for the comparable deformations of both cars, and also reduces the intrusion of the bulkhead into the passenger compartment. The second criterion is the 'end of crash force', the resistance force that prevents the collapse of the passenger compartment. This criterion will have a relation with life-threatening injuries with sufficient survival space in the final stage where an excessive load is applied to the car structures. In the present research, the end of crash force was determined as the maximum barrier force after the engine stopped. For the Move, Wagon R and Civic, the maximum force level was 313, 299, 295 kN, and the end of crash force was 234, 152, 115 kN, respectively.

Comparison of Force between Overload Tests and Car-to-Car Crash Tests

The intrusion into the passenger compartment is shown in Figure 27. The deformation and intrusion were most severe in an overload test. This kind of test can therefore be used to evaluate the passenger compartment strength of the kind when a large crash transmits a massive load to the compartment. The intrusion of Wagon R was not so large compared with the overload test, possibly because the longitudinal member of this car is relatively high with large section thickness, and the structural interaction was good in crash into a Crown.

The maximum force level and end of crash force determined for car-to-car and overload tests are shown in Figure 28. In the car-to-car test, the end of crash force was determined from the structural force since barrier forces could not be determined. The maximum force level is likely to show a correlation between the overload test and the crash into the Crown. Consequently, overload tests can predict the maximum force levels in car-to-car crashes. In Figure 28, the end of crash force of the Civic is seen to be higher in the car-to-car test than the overload test. The main reason is that the force applied to the passenger compartment crashing into the Crown did not reach the severity of the end of crash force determined from the overload test. However, with the Move and Wagon R, there also seem to be some correlations of the end of crash force between the car-to-car and overload tests.

Based on the test results, the overload tests are effective to predict the compartment integrity based on the maximum force level and end of crash force in a crash into a large car. The threshold of maximum force level may be 300 kN and that of the end of crash force may be 250 kN, at least given the performance of the Move when crashing into a large car. In order to determine the criteria or their threshold, more research will be necessary to confirm the effectiveness of the overload test of the compartment integrity in car-to-car tests.

The force path or deformation mode can be different between the overload test and the car-to-car test because the structural interaction varies in both tests or the bottoming-out of the honeycomb occurs in the ODB tests which can make for a different force path around the engine. For example, lateral and vertical mismatches can occur in car-to-car tests, which cannot be predicted in ODB tests. Irrespective of these differences, the maximum force level and end of crash force will be evaluated from the overload tests, which can predict the performance of the passenger compartment integrity in a crash into a large car.

To improve the compartment strength of minicars or small cars, a first priority will be to maintain the end of crash force at a high level. In this stage of the end of the crash, the floor of the car buckles, possibly causing life-threatening injuries to the occupants. The high level of the end of crash force can prevent the passenger compartment from collapsing. The second priority will be increasing the maximum level of the structural force, which ensures balanced deformation between cars in a crash.

The passenger compartment strength seems to be most crucial because it involves the survival space. Furthermore, the compartment strength is most effective when the structural interaction is good, where the occupants can be exposed to the deceleration optimized in ODB tests.

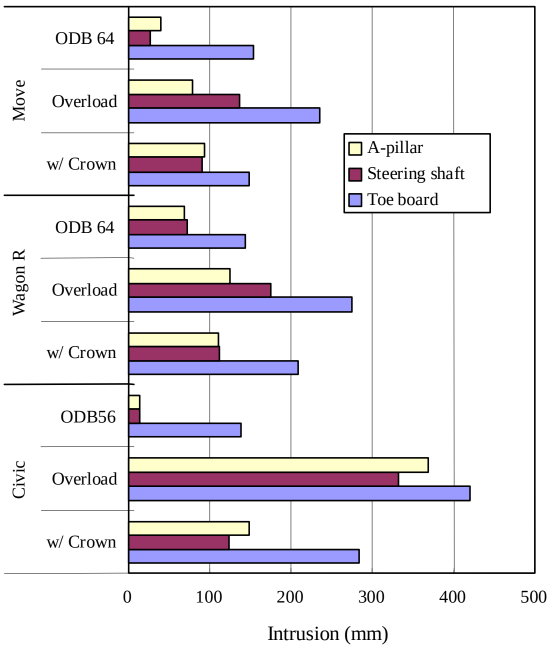


Figure 27. Intrusion into the passenger compartment in ODB test, overload test and crash into a large car.

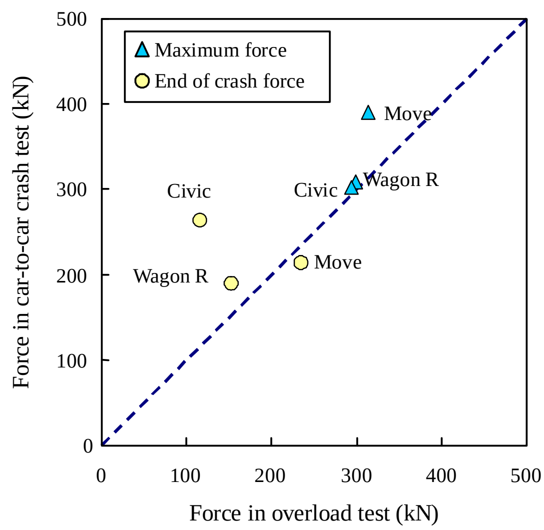


Figure 28. Maximum force level and end of crash force in overload tests and in crashes with Crown.

DISUSSION

We examined test procedures for the assessment of compatibility. Many studies reported in the IHRA Compatibility Working Group confirm that good interaction is essential in preventing override and vertical mismatch of longitudinal members to ensure energy absorption for both cars. After good structural interaction, it is necessary to control the absorption of energy by the vehicle front structure and maintain the passenger compartment integrity.

Test procedures must be selected with these considerations in mind also to improve vehicle compatibility without lowering levels of self-protection. Therefore, we consider it important to use the following combination of three test procedures:

(1) Full frontal impact test with high resolution load cell measurement
(2) ODB test
(3) Overload test

Full frontal tests can assess the structural homogeneity based on the barrier force distributions. The AHOF is an important parameter to assess the potential override. Other criteria will be examined which are effective in predicting the structural interaction in car-to-car crashes. It has been proposed that a honeycomb be attached to the rigid wall [5]. Using this honeycomb, shear connections between the vehicle structures may be evaluated. The footprint of a lateral member like a lower cross member or subframe will also be investigated using this barrier.

PDB tests have the capability to evaluate the structural interaction and force level by the PDB deformation. In particular, these tests can assess the effectiveness of lateral members directly compared with full frontal rigid barrier crash tests. Research on the above test procedures will continue.

CONCLUSIONS

A series of crash tests are carried out to assess the vehicle compatibility. The results are summarized as follows:

1. In full rigid barrier crash tests, barrier force distributions are useful to evaluate the structure. The AHOF is an important criterion for force distributions, and has a correlation with vehicle mass and longitudinal member height. The force of subframe attachment point seen in footprint of the barrier force.
2. PDB test can clarify the effectiveness of lateral members more directly from the barrier deformation. The car acceleration in the PDB test is similar to that in the ODB test.
3. In ODB tests, the maximum barrier force is proportional to the vehicle mass, which may be a parameter to evaluate the aggressiveness.
4. From current ODB tests, some vehicles show balanced upper and lower barrier forces, and others have a large lower barrier force compared with the upper barrier force.
5. Overload tests are effective for the assessment of the passenger compartment strength. The end of crash force and maximum force can be criteria for overload tests. These forces have correlations with those in a crash into a large car where excessive load is applied on the passenger compartment.

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