

TEST PROCEDURES TO EVALUATE VEHICLE COMPATIBILITY

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ABSTRACT

Test procedures for evaluating vehicle compatibility were investigated based on accident analysis and crash tests. This paper summarizes the research reported by Japan to the IHRA Compatibility Working Group.

Passenger cars account for the largest share of injuries in head-on collisions in Japan and were identified as the first target for tackling vehicle compatibility in Japan.

To ascertain situations in collisions between vehicles of different sizes, we conducted crash tests between minicars and large cars, and between small cars and large cars. The deformation and acceleration of the minicar and small car is greater than that of large car.

ODB, Overload and MDB tests were performed as procedures for evaluating vehicle compatibility. In overload tests, methods to evaluate the strength of the passenger compartment were examined, and it is found that this test procedure is suitable for evaluating the strength of passenger compartments. The MDB test is a procedure taking into account the effects of vehicle mass in evaluating vehicle compatibility. The MDB tests with three different barrier faces indicated problems with MDB override and bottoming-out, which have a great effect on the behavior of the test vehicles.

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⁽¹⁾ 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 both to ascertain the current state of compatibility issues in Japan and to evaluate and improve compatibility performance in 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. Japan considers the activities of the IHRA to be significant activities that will inform future legislation and regulation, and has conducted research with the aim of making an active contribution to these activities. This report summarizes the results of fleet studies, structural surveys, accident analysis and crash tests that Japan has conducted and reported to the IHRA Compatibility Working Group.

METHODOLOGY

Fleet Studies

Vehicle compatibility is strongly related to fleet composition, and fleet studies can identify which vehicle types, vehicle mass and other such properties of the vehicles in a country's fleet should be subject to compatibility.

The four-wheel vehicles used in Japan were classified into different types and the proportion of each among registered vehicles was surveyed. To examine further passenger cars with the greatest number of registrations, passenger cars were divided into classes

and the number of vehicles in each class ascertained. From this analysis, we identified those vehicle types with high exposure.

Vehicle mass are factors with great effects on compatibility. The distributions of vehicle curb mass in Japan were examined on the basis of the 113 passenger car models newly registered in 1998. Such data were provided by the Japanese IHRA Side Impact Working Group. Total registrations of these models accounted for 70% of the new four-wheel vehicle registrations in 1998.

Structural Surveys

The dimensions and locations of the members of a vehicle have a great effect on the structural interactions between them in a crash. To survey the dimensions of members of current cars, we used the data on the 113 passenger car models (i.e., the same data as used in vehicle mass distribution analysis). The dimensions used were the top and bottom edge heights of the front end of the longitudinal members, cross member bottom-edge height and shock absorber height. Since interactions with the longitudinal member in a crash are especially significant, the distributions of the top- and bottom-edge heights of longitudinal members were determined on the basis of the data.

Accident Analysis

To address the issue of vehicle compatibility in Japan, it is necessary to identify priority target vehicles and their numbers. We therefore used global accident data (1995) to find the proportion of head-on collisions in all accidents and further identify the vehicle type with the largest proportion of such collisions.

Passenger cars were grouped into classes, and the ratios of fatal and serious injuries of the drivers in subject and other cars were examined. Using this method, the effect of velocity is not a major factor, and the compatibility of the car itself can be evaluated. This analysis reveals which classes of passenger car present significant vehicle compatibility issues in Japan.

Crash Tests

To examine the car deformation and the injury risk to drivers in crashes, offset frontal car-to-car crash

tests were performed between cars of different sizes. Moving deformable barrier (MDB) tests and overload tests were also conducted to examine tests as part of our attempt to find fitting methods to evaluate compatibility. Table 1 shows the test matrix.

Table 1.
Test matrix

Test	Car model	Velocity (km/h)	Mass (kg)	Overlap ratio	Remarks
Car-to-Car	Car A (small car)	55.9	1180	50%	with driver dummy
	Car C (large car)	55.9	1595		with driver dummy
Car-to-Car	Car B (minicar)	55.9	929	50%	with driver dummy
	Car C (large car)	55.9	1595		with driver dummy
MDB test	Car B (minicar)	0	1263	40%	with driver and passenger dummy
	MDB (FMVSS 214)	111.6	1367		FMVSS 214 barrier face
MDB test	Car B (minicar)	0	1258	40%	with driver and passenger dummy
	MDB (FMVSS 214)	112.4	1369		ECE R94 barrier face
MDB test	Car B (minicar)	0	1260	40%	with driver and passenger dummy
	MDB (FMVSS 214)	112.3	1368		2-stage barrier face
Overload	Car A (small car)	80.0	1095	40%	without dummy ECE R94 barrier face
Overload	Car B (minicar)	80.0	845	40%	without dummy ECE R94 barrier face

Car-to-car crash tests - To ascertain the present condition and problems in car-to-car crashes, we conducted frontal crash tests between small car (car A) and large car (car C) and between minicar (car B) and large car (car C). Overlaps were 50% for smaller cars, and the impact velocity of each car was 56 km/h. We compared the deformation, acceleration and dummy injury parameters of the two cars. The results were then compared with those for the overload tests and MDB tests and examined the validity of the tests and related problems.

Overload tests - Obviously, the structural integrity of the passenger compartment secures survival space in collision, is important for the effective operation of restraint devices and is fundamental to self-protection⁽²⁾. To prevent the collapse of the passenger compartment in a car-to-car collision, the strength of the passenger compartment (F_{max}) should be greater than the final strength (F_{end}) of the front structures of the other vehicle⁽³⁾.

Overload tests were conducted for a small Japanese car, and for a minicar to evaluate the strength

of the passenger compartment. The tests were performed at 80 km/h and with 40% overlap on the ECE R94 barrier to completely collapse the passenger compartment. For measuring passenger compartment strength, the barrier force and the acceleration of the bottom of the passenger-side B pillar were used. The barrier forces observed in the overload tests (F_{max}) were compared with those in the offset deformable barrier (ODB) tests (F_{end}) at 64 km/h to determine the possible relationship between F_{max} and F_{end} .

MDB tests - MDB tests are one way of evaluating vehicle compatibility while accounting for the effects of vehicle mass. Since the in-depth accident data showed that the proportion of the collision with impact angle zero and 30-40% overlap is the largest, we performed collinear MDB tests at 40% overlap. To reproduce car-to-car collisions at a velocity of 56 km/h, we crashed the MDB (FMVSS trolley) into stationary small cars (car A) at 112 km/h.

To survey the effects of the barrier, we performed experiments using ECE R94 and FMVSS 214 barrier faces. And to prevent MDB override and bottoming-out, an MDB test was conducted with a two-stage barrier face⁽⁴⁾ 700 mm depth mounted 180 mm above the ground (Figure 1). The results were compared with those from car-to-car crash tests.

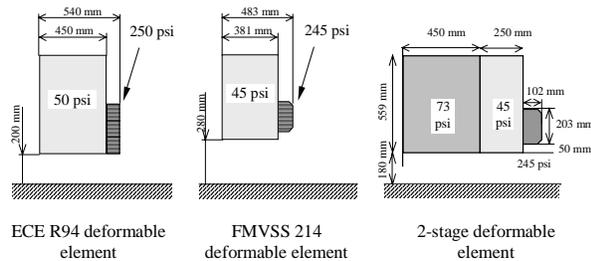


Figure 1. Deformable elements of MDB.

RESULTS

Fleet Studies

The total number of four wheel-vehicle registrations in Japan was 69,528,110 at the end of August 1999 (Figure 2). Among them, passenger cars accounted for 50,601,149 (72.8%) and trucks for 18,690,426 (26.9%). The number of passenger cars increases year by year, while the number of trucks shows no significant change. Therefore, given the

number of registrations, the passenger car is the most important to improve compatibility in vehicle fleets in Japan.

Passenger cars were grouped into classes, and the number of registrations in each class is shown in Figure 3. The proportions of small and medium sedans tend to fall from year to year, and those of minicars, station wagons and minivans to rise. In 1998 SUVs were 5.0% of total registrations, which form a lower proportion in Japan than in the United States and Australia.

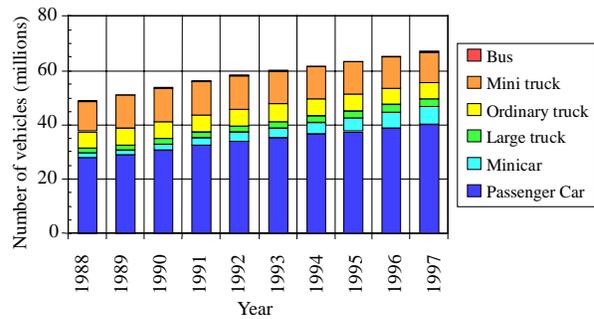


Figure 2. Vehicle registrations in Japan (1988-1997).

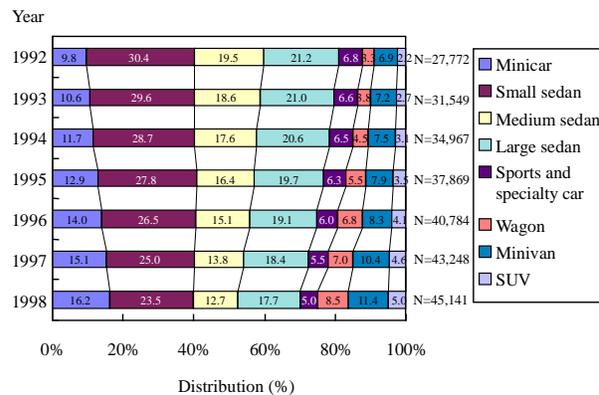


Figure 3. Registration of passenger cars by car class.

From the data on the 113 models of passenger car newly registered in 1998, the distributions of curb mass of cars in Japan were obtained (Figure 4). Curb mass is distributed from 700 kg to 1,800 kg (95% interval), and the average mass is approximately 1,150 kg (1998). This represents an increase of approximately 70 kg from the 1991 average of 1,080 kg. Reasons for this increase in mass appear to be the larger size of vehicles used in Japan such as minivans and SUVs as well as full frontal impact test that became mandatory in 1994, and side impact test mandatory as of 1998.

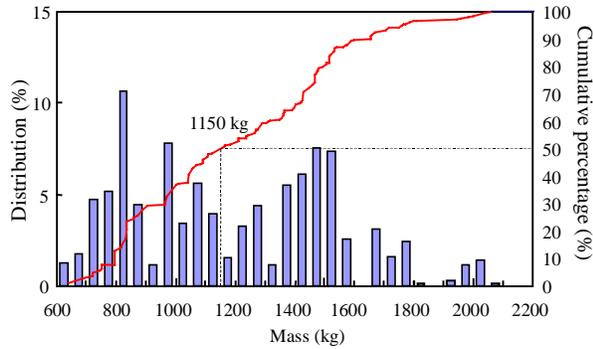


Figure 4. Vehicle mass distribution (1998).

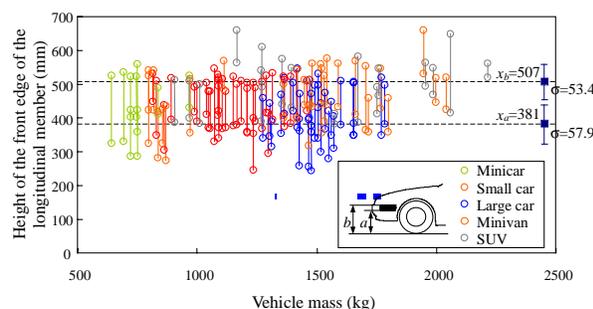
Structural Surveys

The front-end dimensions of the 113 passenger car models newly registered in 1998 were investigated, and the weighted averages for heights of members were obtained from the number of vehicles sold. The average dimensions of the principal members are as follows:

- Longitudinal member top-edge height 504 mm
- Longitudinal member bottom-edge height 376 mm
- Cross member bottom-edge height 256 mm
- Front shock absorber top-edge height 788 mm

These figures are similar to those given in European vehicle survey data. A 1991 survey found cross member bottom-edge height to be 242 mm, so the ground clearance of vehicles has increased somewhat.

Figure 5 shows the distributions of the top-edge and bottom-edge heights of the front end of longitudinal members. The average of the top-edge height is 507 mm and the average bottom-edge height 381 mm. Although the longitudinal member heights of many cars are nearly average, many SUV models have higher longitudinal members than the average, and exhibit great variation.



Note: The averages weighted by vehicle registrations for top and bottom heights of longitudinal member edges are 504 and 376 mm

Figure 5. Distributions in height of front edges of longitudinal members.

Accident Analysis

In the present study, accidents in Japan were analyzed on the basis of global data in 1995. Figure 6 shows the number of fatal or serious injuries of drivers in car-to-car collisions by type of accident. Of 13,157 fatal or serious injuries of drivers, the largest number of 4,372 (33%) was in head-on collisions. Figure 7 classifies these drivers in head-on collisions broken down by type of vehicle. The largest number of 680 was in collisions between passenger cars, and 390 were in collisions between passenger cars and minicars. The total of these two groups is 1,075 (44%). Therefore, from the results of accident studies there is a plurality of fatalities and injuries in car-to-car collisions in Japan in head-on collisions between passenger cars.

Global data (1993-96) were employed to divide passenger cars into classes, and the ratio and the numbers of fatal and serious injuries to the drivers in the subject cars in comparison to the other cars were obtained (Table 2). While minicars exhibit a high fatality and a serious injury rate and a large number of accidents, SUVs exhibit high aggressivity but relatively few accidents. Therefore, the self-protection of minicars is another important issue in accidents in Japan.

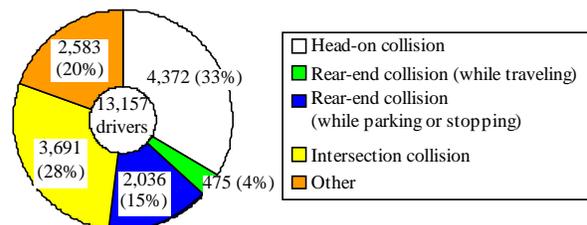


Figure 6. Drivers sustaining fatal or serious injuries by type of vehicle-to-vehicle collisions (1995).

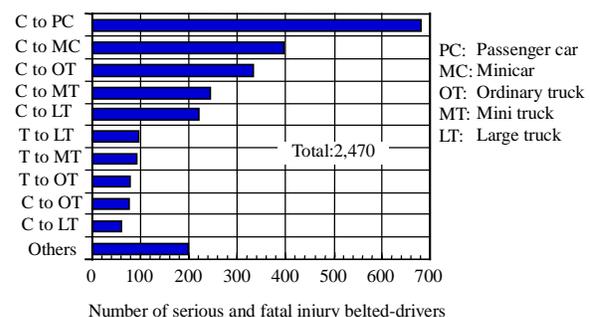


Figure 7. Number of fatal and serious injuries to belted drivers by type of head-on collision (1995).

Table 2.

The ratios of serious or fatal injuries in subject cars to other cars in head-on collisions (1993-1996)

Cars in collision	All drivers	Belted drivers
Minicar vs. Sedan 	5.3:1.0 (553:104)	5.4:1.0 (328:61)
Sedan vs. Sedan 	1.0:1.0 (1938:1938)	1.0:1.0 (1084:1084)
Mini van vs. Sedan 	0.62:1.0 (117:189)	0.77:1.0 (73:95)
SUV vs. Sedan 	0.25:1.0 (35:142)	0.25:1.0 (20:81)

(): Number of injuries

Crash Test

Car-to-car crash test - Offset frontal car-to-car crash tests were performed with an overlap of 50% and an impact speed of 56 km/h between a small car (car A) and a large car (car C), and between a minicar (car B) and a large car (car C).

In crash between small and large cars, the longitudinal member of each car impacted the other's bumper beam; there was no underriding, and interaction was good (Figure 8). There was extensive deformation to the passenger compartment of car A, but hardly any to that of car C. The acceleration-time histories of both cars are shown in Figure 9. The level of the acceleration in car A is slightly higher than that in car C. However, the deformation of car A is larger than car B as shown in Figure 10. The steering column of car A was moved over 100 mm, and toe board intrusion was over 250 mm.

Figure 11 shows injury parameters for the drivers. Injury parameters related to intrusion such as femur force and tibia index grew with the extent of passenger compartment intrusion in car A; the tibia index for car A exceeds the reference value (1.3).



Car A Car C

Figure 8. Car A and car C after impact.

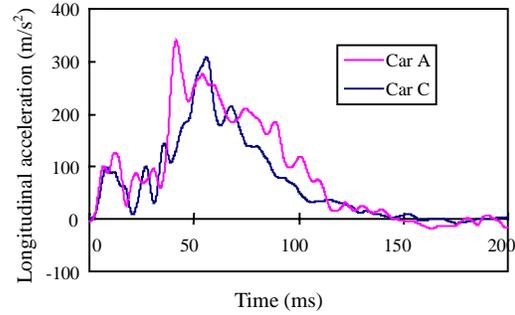


Figure 9. Acceleration-time histories for car A and car C.

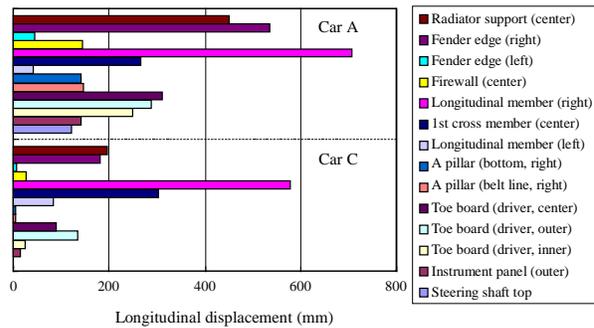


Figure 10. Deformation of car A and car C

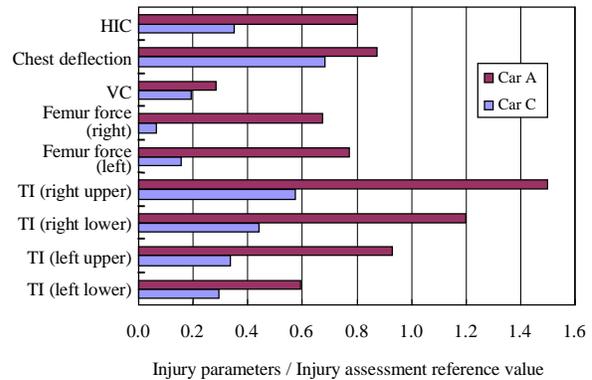


Figure 11. Driver injury parameters in crash between car A and car C.

In crash between minicar and large car the deformations were not uniform due to poor interaction (Figures 12 and 13). The minicar exhibited underriding of the large car. The longitudinal member of each car crashed into the space between the other's longitudinal member and tire, and longitudinal members showed no extensive deformation. However, the tire of car B crashed into the bumper beam of car C, and the fork effect of the longitudinal member of car C was diminished. This lateral mismatch resulted in local

deformation of the wheel house and extensive deformation of the (right-side) toe board of car C.

Figure 14 shows the acceleration-time histories. The acceleration of car B is high, whereas that of car C is low. The deformation of the car is shown in Figure 15. Due to high strength of the passenger compartment, the intrusion of car B is small. Since car B had high acceleration and intrusion into the passenger compartment, the injury parameters related to both acceleration and intrusion are high; HIC is 962, and the tibia index exceeds the reference value (see Figure 16). However, the tibia index of the driver in car B is not necessarily higher than that in car A because the intrusion of the car B is smaller than car A. Though the injury parameters for car C are low, the tibia index exceeds the reference value (1.3) due to local deformation of the wheel house.

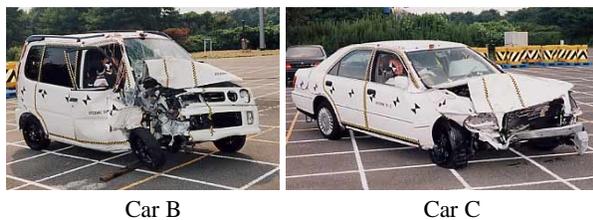


Figure 12. Car B and car C after impact.

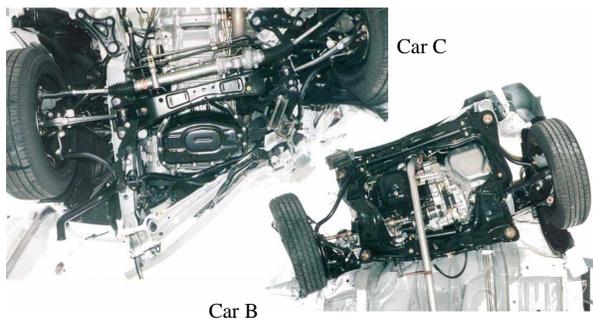


Figure 13. Lateral mismatch of car B and car C.

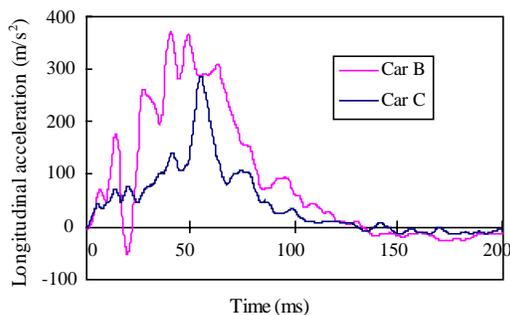


Figure 14. Acceleration-time histories for car B and car C.

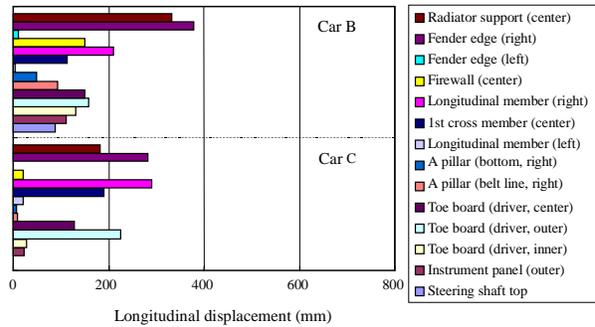


Figure 15. Deformation of car B and car C.

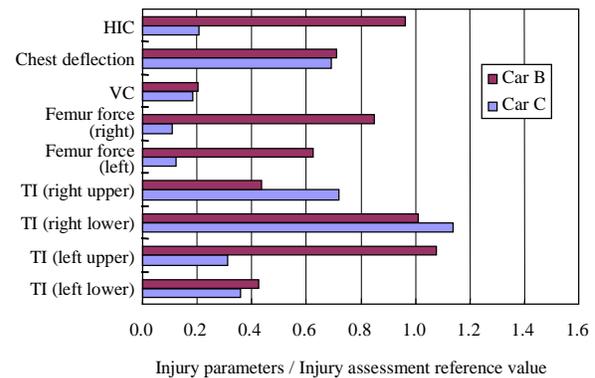


Figure 16. Driver injury parameters in crash between car B and car C.

When comparing the crash of car A and car B into car C, the injury risk is not only related with car mass. The high strength of the passenger compartment of car B is effective even with the poor interaction.

Overload Test - Overload test of the small car (car A), and that of minicar (car B) were conducted. Both car A and car B showed side sill bending, large intrusion of the instrument panel and large displacement of the steering column upwards and to the rear. The test showed no more survival space in the passenger compartment due to the crash.

Figure 17 shows the force-time histories derived from the barrier load cells and B pillar acceleration on the passenger side that suffered little deformation. To derive force from acceleration, the product of longitudinal acceleration and car mass was used. The curve indicates that barrier load was greatest at 66 ms and load from the B pillar greatest at 74 ms. Examination of vehicle deformation at each of these times (Figure 18) revealed that the instrument panel intrusion into the passenger compartment began after 66 ms. After 74 ms the side sill buckled and the force

derived from B pillar acceleration on the passenger side decreased.

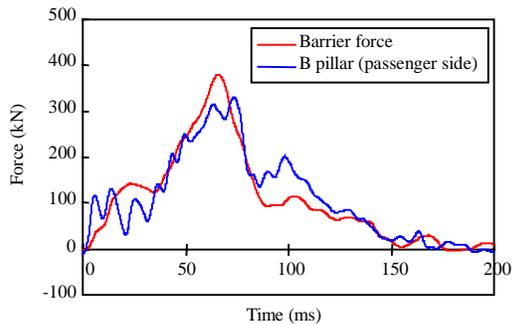


Figure 17. Force-time histories of car A in overload test.

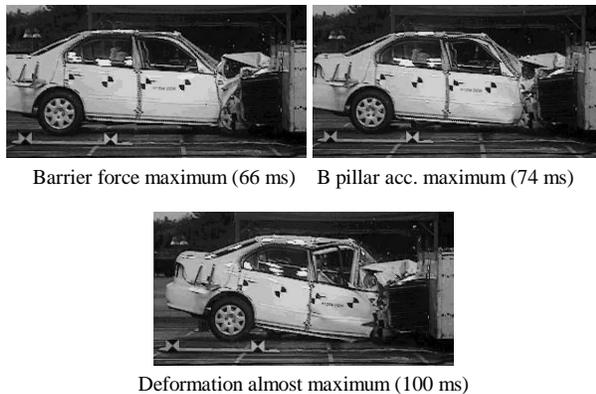


Figure 18. Deformation of car A in overload test.

Figure 19 shows the force-time histories for car B. Barrier load was greatest at 50 ms, and B pillar load greatest at 68 ms. Like car A, the instrument panel intrusion into the passenger compartment began at the time of maximum barrier load, and the bending from the center of the side sill began after the force obtained from the passenger-side B pillar reached the maximum (Figure 20).

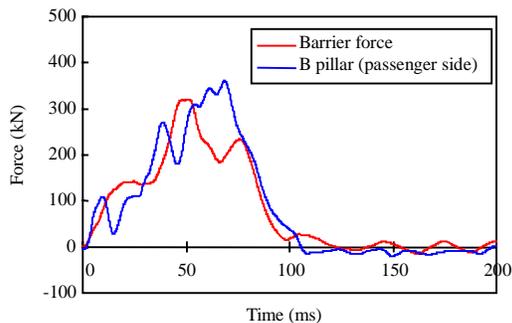


Figure 19. Force-time histories of car A in overload test.

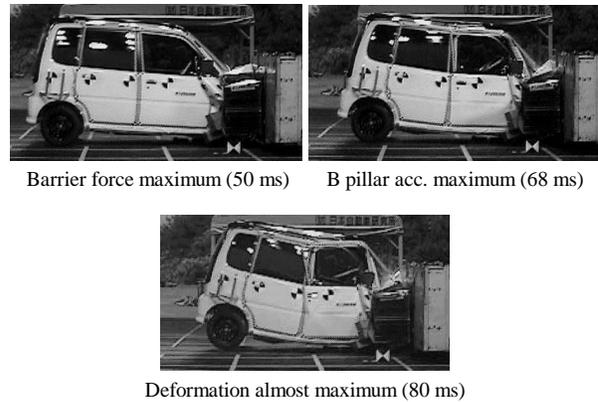


Figure 20. Deformation of car B in overload test.

Evaluation of the strength of the passenger compartment varies with load measurement location and procedures. Table 3 gives the characteristics of passenger compartment strength derived from barrier load cells and passenger-side B pillar acceleration, and the car A and car B passenger compartment strength derived from these. In car-to-car collisions the force of impact is transmitted through the impact plane. Therefore, passenger compartment strength measured by barrier force in overload tests may be directly used to predict the passenger compartment collapse in car-to-car collisions.

Passenger-side B pillar acceleration reaches maximum immediately prior to the buckling of the side sill, after which time force is inadequately transmitted through these members. Therefore, a measurement of passenger compartment strength derived from B pillar acceleration may be considered to represent the strength of these members and the survival space in the final stage.

Table 3.
Evaluation of compartment strength

Measurement locations	Features	Compartment strength	
		Car A	Car B
Barrier force	• Evaluation of crash force on the interface		
	• Maximum when instrument panel intrudes	381 kN	321 kN
	• Effect of inertial forces of engine is large		
B pillar (acceleration)	• Evaluation of collapse force level at side sill	331 kN	360 kN
	• Depending on calculated mass		
	• Great influence of fluctuation of the acceleration pulse		

Figures 21 and 22 show the force-displacement characteristics of car A and car B, broken down by impact velocity. Force-displacement characteristics describe the similar curve, regardless of velocity, and the deformation mode at 80 km/h may be considered to match those at lower velocities. The maximum force of car A in the overload test and in the 64 km/h ODB test are near matches of around 330 kN. However, the energy absorption in this force level can be obtained from the overload test. For car B, on the other hand, the maximum force is 360 kN in the overload test, which is higher than that in the ODB test (329 kN). Therefore, whereas car B did not reach its maximum passenger compartment strength at 64 km/h, the overload test makes it possible to determine the actual passenger compartment strength.

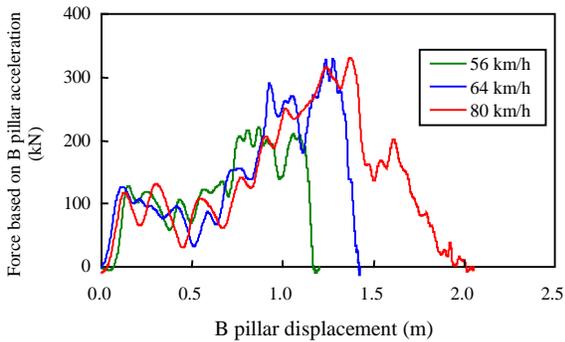


Figure 21. Force-displacement characteristics for various impact velocities (car A).

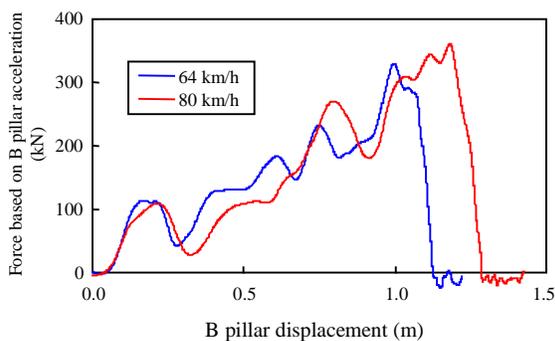


Figure 22. Force-displacement characteristics for various impact velocities (car B).

The maximum barrier forces in overload test and 64 km/h ODB test were compared in Figure 23. In ODB tests, maximum barrier force increases with vehicle mass. Comparing these values with the maximum force

in overload tests of car A and car B, we find that they correspond to the maximum loads in 64 km/h ODB test of a 1,620 kg car A and a 1,920 kg car B. Therefore, we may infer that the passenger compartments of car A and car B will not collapse before vehicle deformation reaches the extent observed in 64 km/h ODB test. The figure also indicates that car A and car B passenger compartments would not collapse in collisions with car C, and in actual car-to-car crash test, the passenger compartments of car A and car B were preserved.

Deformation is less uniform in actual car-to-car collisions than in an overload test. Since various deformation modes occur in car-to-car collisions, it is necessary to evaluate passenger compartment strength in overload tests on the basis of various parameters such as instrument panel intrusion and side sill strength. The differences in vehicle deformation observed in the overload test and car-to-car crash test also require further study.

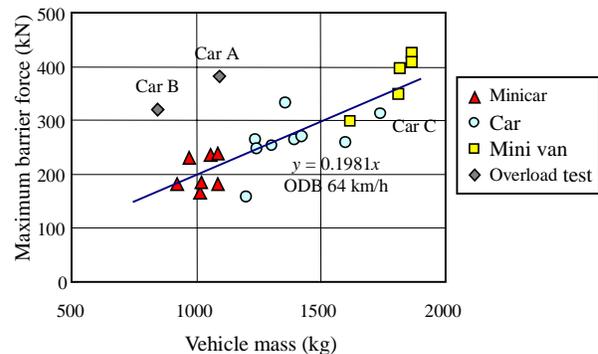


Figure 23. Barrier forces in overload test and 64 km/h ODB test (JNCAP).

MDB test - In theory, the MDB test is one way of reproducing car-to-car collisions in terms of acceleration and deformation. We conducted an MDB test with three barrier faces: the ECE R94 barrier face, the FMVSS 214 barrier face and a two-stage barrier. We compared the results with those from car-to-car crash tests.

Figure 24 shows acceleration-time histories. Since overlap was 50% in the car-to-car collisions and 40% in the MDB test, acceleration in this test was lower than in the car-to-car collisions. Override of the MDBs occurred for all barriers. In the MDB test with ECE barrier face, the acceleration of the car was high due to bottoming-out of the barrier face. Since the FMVSS

barrier ran fully on top of the test vehicles, acceleration fell from 50 ms. Acceleration with the two-stage barrier was lower than in the car-to-car collisions, but its crash pulse was closest to the car-to-car collisions.

Figure 25 compares deformation in the MDB tests. Tests with the two-stage barrier face exhibited A pillar deformation, steering column movement and toe board intrusion most resembling those in the car-to-car collisions. In tests with the ECE and FMVSS barriers, MDB override resulted in greater deformation of the fender edge than of the longitudinal member.

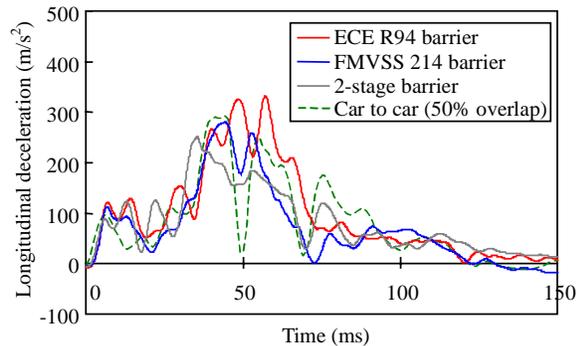


Figure 24. Car acceleration in MDB test with various barrier faces.

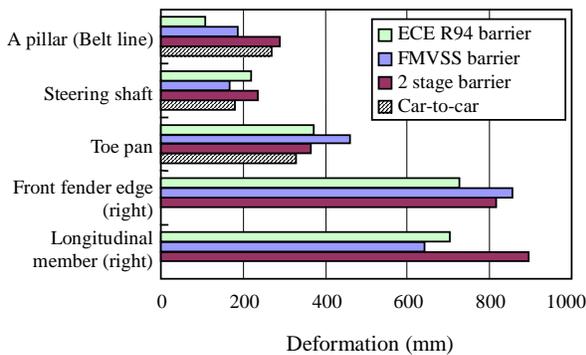


Figure 25. Car deformation in the MDB test with various barrier faces.

Vehicle behavior in an MDB test using a two-stage barrier is presented in Figure 26. With this barrier MDB override occurs past 60 ms, but acceleration already starts falling by this time (Figure 24) and did not appear to have a great effect on impact phenomena. With the ECE R94 and FMVSS 214 barriers, bottoming-out and override was starting at 40 ms, greatly affecting acceleration and deformation.

Considering acceleration, deformation and MDB overriding, crash tests with the two-stage barrier (180 mm ground clearance) reproduce car-to-car collisions more closely than with the other barrier face and ground clearance examined in the tests.

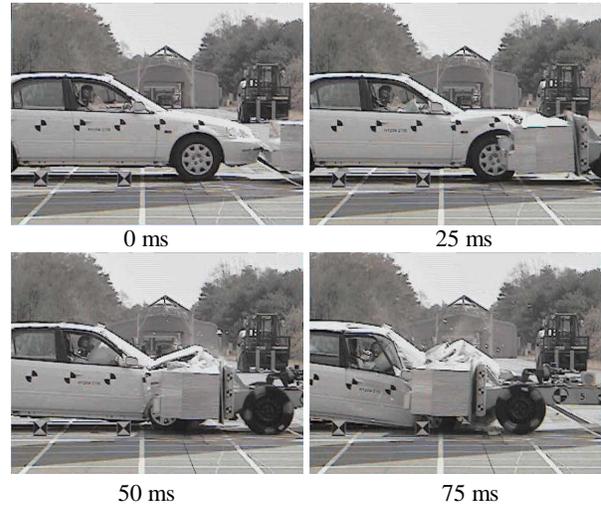


Figure 26. Vehicle behavior in MDB test (2-stage barrier).

DISUSSION

On the basis of fleet studies, accident studies and crash tests, we examined test procedures for the evaluation 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⁽⁵⁾. Thus, in order to improve compatibility, it is necessary to control the absorption of energy by the vehicle front structure and maintain the passenger compartment integrity in good structural interaction. Test procedures must be selected with these considerations in mind. Further, test procedures must 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 against rigid walls with high resolution load cell measurement
- (2) ODB test
- (3) Overload test

Remarks and some possible criteria for these tests are as follows:

- (1) We did not examine the load distributions in full frontal tests in our research, but it will be effective for good interaction to evaluate the homogeneity from the force distribution of barrier load cells. To allow homogeneous evaluation, a center of force and coefficient variation can be among the criteria.
- (2) ODB test is capable of evaluation of energy absorption in the front of vehicles, acceleration pulse and injury risk to occupants. To evaluate the self-protection and aggressivity of the car, the maximum force level in this test can be also one of the criteria.
- (3) For correct measurement of passenger compartment strength, both acceleration of the passenger compartment and barrier force may be necessary. Further research is required on impact velocity, methods of measuring passenger compartment strength, thresholds and differences in deformation modes in car-to-car collisions.

This combination of tests allows control of vehicle interaction, the extent of acceleration and intrusion, and is highly likely to lead to greatly improved vehicle compatibility. However, the crash conditions and criteria that should be used in the individual tests require more detailed study.

It is possible that MDB test may reproduce the acceleration and vehicle deformation observed in car-to-car collisions. However, MDB override and barrier bottoming-out occurred in the three tests we performed, greatly affecting the behavior and deformation mode of the test vehicles. More detailed research is required to resolve these problems, and at this time we are considering tests with fixed deformable barriers (FDB) based on three tests described above to be more capable of evaluating vehicle compatibility.

CONCLUSIONS

This paper summarizes the results of fleet studies, structural surveys and crash tests reported from Japan to the IHRA Compatibility Working Group. Our conclusions are as follows:

1. From the number of vehicles registered as well as accidents in Japan, we find that passenger cars are the priority target for vehicle compatibility in the Japanese transportation environment.

2. We surveyed front-end vehicle dimensions of car models and identified the average dimensions of such members as the longitudinal member and cross member.
3. Vehicle compatibility requires the evaluation of passenger compartment strength. Overload tests were performed using a minicar and a small car. This kind of high-velocity test can be one of the methods to evaluate the passenger compartment strength.
4. MDB tests were performed with three different barrier faces. In spite of the benefit of the MDB test to reproduce acceleration and deformation, there are problems with MDB barrier override and bottoming-out, and these proved to greatly affect test vehicle behavior and deformation.
5. Vehicle compatibility requires control of energy absorption by the vehicle front structures and intrusion into the passenger compartments in good structural interaction between the cars. In this light, we consider the combination of full frontal impact tests against rigid walls to measure load distribution, ODB test and overload test to be appropriate for the evaluation of vehicle compatibility.

REFERENCES

1. Gabler, C. H., Hollowell, T. W., "NHTSA'S Vehicle Aggressivity and Compatibility Research Program", 16th ESV, Paper No. 98-S3-O-01, 1998.
2. Steyer, C., Diaboine, A., Delhommeau, M., Delannoy, D., "Taking Compatibility Aspects into Account When Designing Vehicles", VDA Technical Congress, Frankfurt, 1999.
3. Zobel, R., 'Accident Analysis and Measures to Establish Compatibility', SAE Paper 1999-01-0065, SAE Congress, 1999.
4. Sugimoto, T., Kadotani, Y., Ohmura, S., "The Offset Crash Test—A Comparative Analysis of Test Methods", 16th ESV, Paper No. 98-S1-O08, 1998.
5. Edwards, J., Happian-Smith, J., Byard, N., Davies, C., Hobbs, A., "Compatibility—the Essential Requirements for Cars in Frontal Impact", IMechE, Conference Transactions, Vehicle Safety 2000, pp.3-17, 2000.