THE OFFSET CRASH TEST -A COMPARATIVE ANALYSIS OF TEST METHODS

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ABSTRACT

This research will discuss the issue of how the currently used frontal crash tests correlate to actual accidents. The following data will be presented in relation to this:
1. Results of offset crash tests now being conducted, and results of vehicle-to-vehicle crash tests, especially results of crash tests in which the vehicles have different weights.
2. Why do such differences occur?
3. Differences between the results of tests with moving deformable barriers (MDB) which are being studied by the National Highway Traffic Safety Administration (NHTSA) and results of vehicle-to-vehicle crash tests.
4. Results of modifications to test methods
The following aspects of the above mentioned issues will be discussed:
1. Important items and information to be considered in studying crash test methods to be used in the future.
2. Information which needs to be taken into consideration in developing cars in the future.

INTRODUCTION

In response to the need to improve crashworthiness, various countries have proposed and implemented a variety of test methods in order to provide regulations and safety information. Recently, offset crash tests have come into widespread use in addition to full frontal crash tests or oblique impact tests. In actual accidents, chassis deformation and intrusion into the cabin has been observed in many cases. In addition, passenger deaths have been reported in conjunction with chassis and cabin deformation. Therefore, with the primary objective of securing cabin space and thereby reducing passenger deaths, a great deal of research has been conducted on offset crash tests, as well as on the body frame structure in order to improve passenger survivability. Full frontal crashes are considered useful for evaluating the performance of safety devices which restrain passengers during a crash. Offset crashes are considered appropriate for evaluating cabin deformation caused by the impact loads on the vehicle during a crash. As has already been described in a wide range of literature on the subject, in a certain sense, these two test methods involve evaluating mutually contradictory phenomena. This is an extremely serious and difficult problem for automobile development engineers who are attempting to improve crashworthiness. Issues which will be critical in discussions of vehicle crashworthiness in the future are:
(1) Does each of these evaluation techniques provide methods and criteria which are suitable for increasing vehicle crashworthiness?
(2) Which of these test methods is useful in developing and evaluating a vehicle?

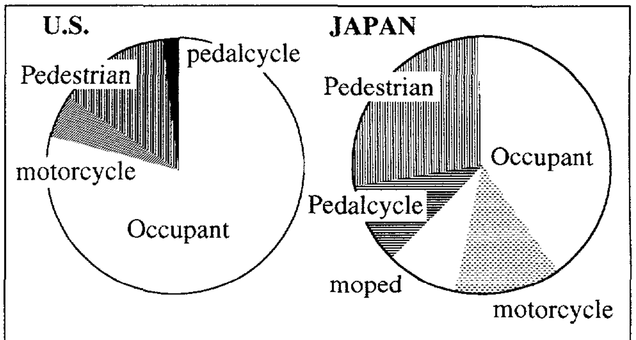
A variety of configurations and conditions have been proposed, especially for offset crashes, so further research and discussion are needed.

An area which is currently a main focus of concern is the types of considerations that are needed for vehicle designs which will provide compatible crashworthiness for both small cars and large cars. This issue is especially important for vehicles which are evaluated with these methods.

This research seeks to verify how crash test methods, either full frontal or offset frontal crashes, are associated with actual accidents. This research also discusses what needs to be done in the future.

BACKGROUND

Among actual accidents, deaths of passengers riding in vehicles may be classified as shown in Figure 1 for Japan and the U.S.



Sources: US; FARS 1995
JAPAN; The Japanese police traffic accident statistics since 1995

Figure 1. Fatalities in traffic accidents

Fatalities of passengers riding in vehicles may be further categorized by the type of accident. There are two general classifications: single-vehicle accidents and vehicle-to-vehicle accidents. The breakdowns for these classifications are shown in Figure 2. As shown in the figures, about half of the accidents are single-vehicle accidents and the other half are vehicle-to-vehicle accidents.

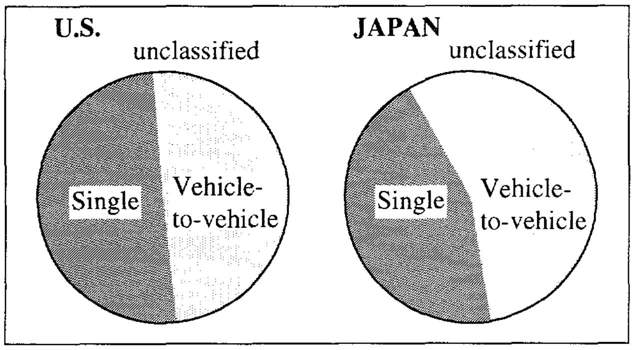
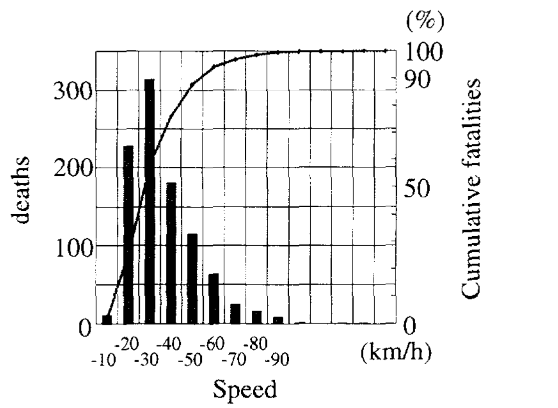


Figure 2. Classification of fatal collisions

Figure 3 presents the numbers of cumulative fatalities and the corresponding barrier equivalent speeds.

Approximately 90% of the cumulative fatalities occur at speeds of 50-55km/h or less.



Source: NASS CDS 1991-1995
head on collisions with belted

Figure 3. Barrier equivalent speed

The conditions for the tests currently being conducted were established based on such information.

We will now consider which types of actual accidents each of the test methods is applicable to. The discussion will be simplified in order to maintain a comprehensive focus on current problems and future trends. For further information on the detailed verifications, the reader is referred to the results of research conducted by various researchers in the course of establishing each of the crash test methods. The frontal crash test methods which are currently used in Japan, the U.S., Canada, Europe, and Australia are listed in Table 1.

Table 1. Test configurations

	JAPAN	U.S.	EUROPE	AUSTRALIA
Regulation	Full flat 50km/h	Full flat 48km/h R/L 0°~30° 48km/h	ODB 56km/h	Full flat 48km/h
Consumer safety information test	Full flat 55km/h	Full flat 56km/h ODB 64km/h	ORB 55km/h ODB 64km/h	Full flat 56km/h ODB 64km/h

The common types of full frontal crash tests into a flat, rigid barrier, are the regulation tests used by the NHTSA in the U.S., Transport Canada in Canada, the Federal Office of Road Safety (FORS) in Australia, and the Ministry of Transport in Japan. This same type of test is also used in the New Car Assessment Program (NCAP), which serves to provide consumer safety information and incorporates some changes (e.g., a higher crash speed). These test methods will now be considered in relation to actual accidents. In vehicle-to-vehicle accidents, vehicles of the same weight may collide head on with almost no offset. In single-vehicle accidents, the vehicle may collide head-on into an object such as a structure. In actual accidents where the vehicle collides into a structure, vehicles may collide into trees, utility poles, or experience under-ride impact into trucks in addition to colliding into flat objects. At the present time it is very difficult to narrow down correlation with macro data. It is difficult to postulate the exact extent to which this test method covers actual accidents. However, it is possible to infer from the statistics on cumulative fatalities that there are cases in which passengers are subjected to rather strong impacts during collisions.

In light of such considerations, the full frontal rigid barrier crash test methods seem extremely useful for evaluating life saving capabilities which would reduce passenger injuries during extremely strong actual impacts. This test method is advantageous in that it allows evaluations under conditions in which driver and passenger impact severities are nearly identical. The offset crash tests conducted in the past few years may be broadly divided between offset rigid barrier (ORB) crash tests and offset deformable barrier (ODB) crash tests.

In the case of offset rigid crashes, offset crashes between vehicles of the same weight during vehicle-to-vehicle accidents and offset crashes into structures during single-vehicle accidents are covered by this method and are considered applicable. However, as in the case of full frontal crashes, there is not a clear association between offset rigid crashes and collisions into trees or utility poles, or underride impact into trucks.

In the case of offset deformable crashes, the results of experiments replicating vehicle-to-vehicle accidents have been used to establish test conditions, such as collision speed and the specifications of the honeycomb (a deformable device), as has been referred to in European Experimental Vehicle Committee (EEVC) and Insurance Institute of Highway Safety (IIHS) research reports. However, there has been little in the way of verification under conditions in which the vehicles involved have different weights. Therefore, in this study we would like to compare the results of such offset deformable crashes with the results of vehicle-to-vehicle tests based on vehicles with different weights. The need for verification using offset crash tests is to determine how well passenger space in the vehicle cabin is protected. This test serves to evaluate cabin deformation, and resistance to intrusion as a result of the collision. Thus, this method can be used to verify how well the cabin and frame in the engine room compartment are able to absorb the impact energy from the collision and distribute the impact forces. As reported in the for EEVC and IIHS research reports, the specifications of the offset deformable barrier (honeycomb) which is used with this test simulates the stiffness of the structure at the front of a vehicle of nearly average weight (normally called a mid-size vehicle). In terms of actual vehicle-to-vehicle accidents, this test seems to simulate vehicle-to-vehicle collisions involving vehicles of average weight or less.

TEST RESULTS

Actual vehicle crash tests were conducted under these offset conditions. Figure 4 illustrates the vehicle deformation results of offset rigid collisions. The offset rigid crash test method (ORB) was used by Auto Motor Sport, a German magazine. Figure 5 illustrates the vehicle deformation results of offset deformable collisions.

Figure 6 compares the deformation results of vehicle-to-vehicle offset crash tests in which both vehicles weighed approximately 1500kg. The vehicle-to-vehicle crash test conditions were a speed of 56km/h for both vehicles and an offset of 50%

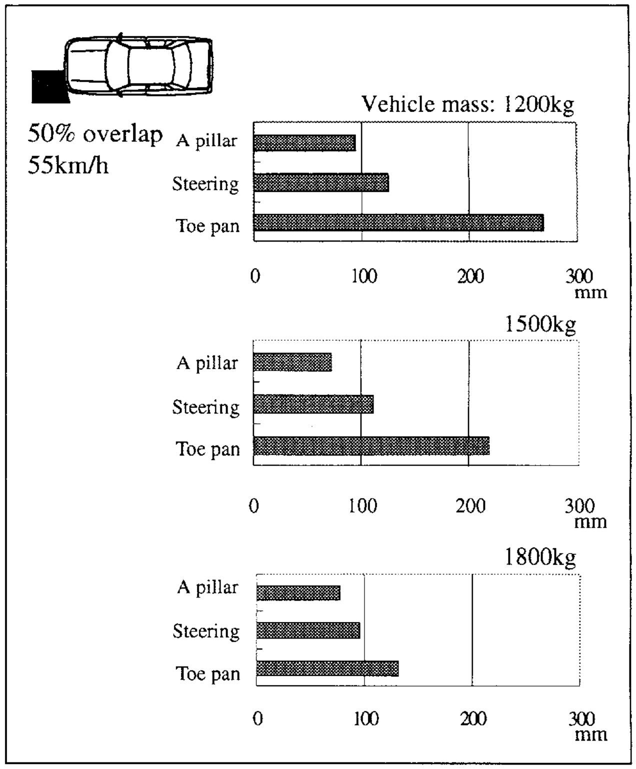


Figure 4. Vehicle deformation (ORB)

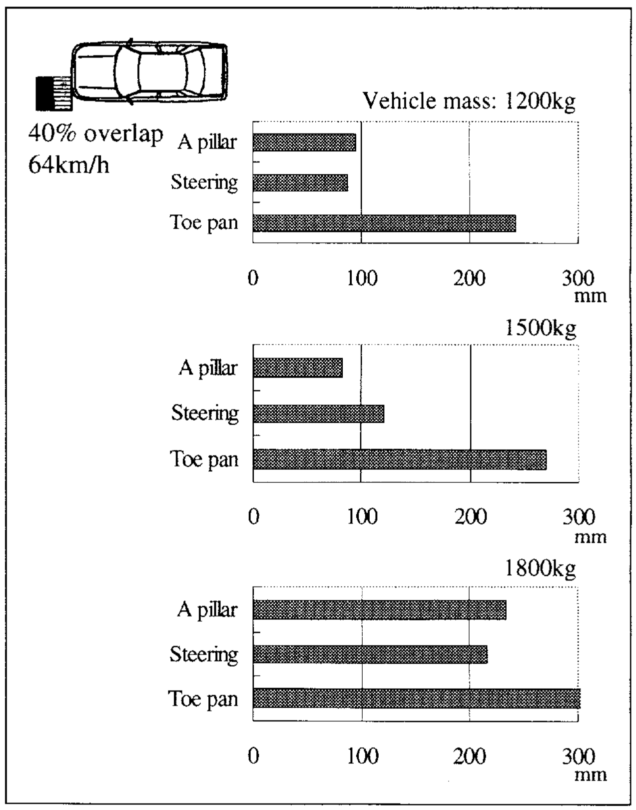


Figure 5. Vehicle deformation (ODB)

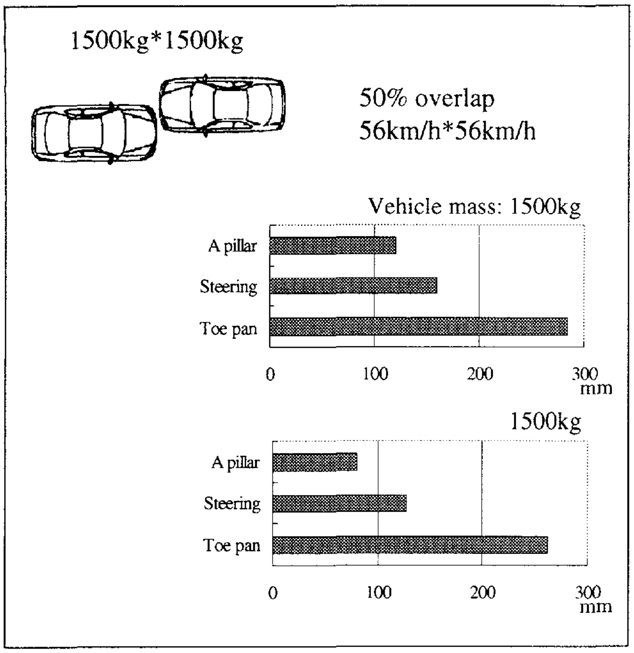


Figure 6. Vehicle deformation (vehicle-to-vehicle)

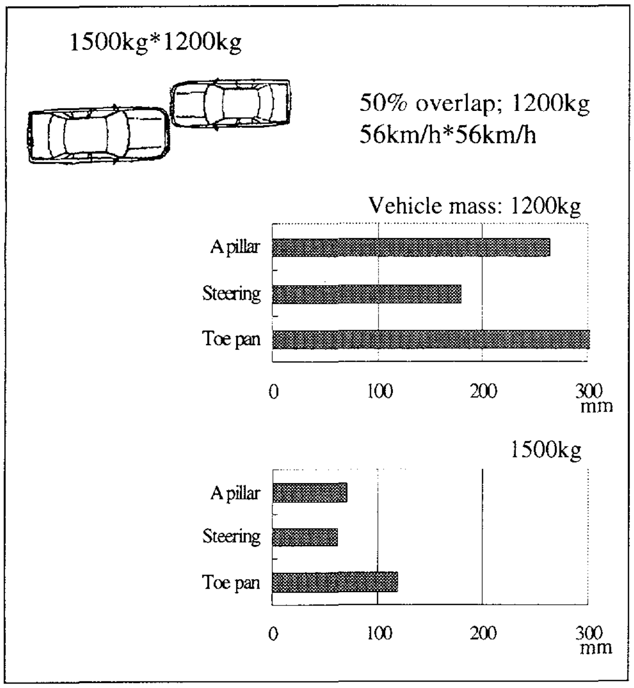


Figure 7. Vehicle deformation (vehicle-to-vehicle)

Figure 7 compares the deformation results of the same type of vehicle-to-vehicle offset crash tests in which one of the vehicles weighed approximately 1200kg, and the other approximately 1500kg.

Figure 8 compares the deformation results of the same type of vehicle-to-vehicle offset crash tests in which one of the vehicles weighed approximately 1200kg, and the other approximately 1800kg.

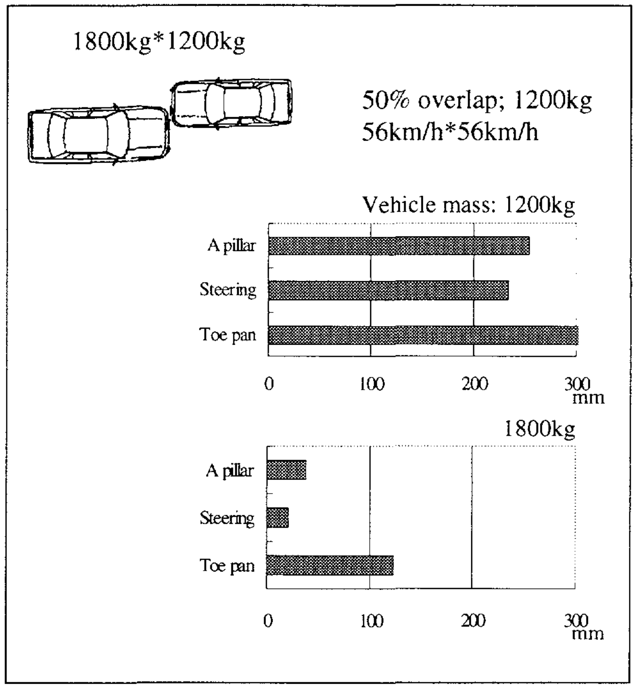


Figure 8. Vehicle deformation (vehicle-to-vehicle)

ANALYSIS

As illustrated above, the results for vehicle-to-vehicle offset crash tests in which both vehicles weighed approximately 1500kg were consistent with the offset deformable crash test results. When the vehicles had different weights, there is a significant difference between the vehicle-to-vehicle crash test results and the barrier crash test results.

As mentioned above, offset rigid barrier collisions simulate collisions between vehicles of the same weight, or collisions into structures. In contrast, offset deformable barrier collisions are essentially offset collisions between vehicles of average weight. However, the results of the offset deformable barrier crash tests indicate that if the colliding vehicle weighs more than average, (e.g.,1800kg) a bottoming out phenomenon will occur due to the characteristics of the deformable barrier (i.e., the honeycomb). As a result it would seem that an actual vehicle-to-vehicle crash is not simulated in such cases. Similar problems have already been pointed out among researchers; this will remain a topic for future study.

Nonetheless, this cannot be set aside as a simple "issue". In other words, vehicles which are developed in order to obtain good evaluation results using such test methods may create a number of problems under actual road conditions.

One such problem is an increase in vehicle weight. It is inevitable that weights will increase as a result of improvements in crashworthiness. Unfortunately, excessive increases in vehicle weight remain a significant problem. Specifically, vehicles whose structures are designed based on test conditions and evaluation criteria which are significantly different from actual accident conditions will not contribute appropriately to efforts to improve crashworthiness under actual road conditions. Also this is a problem of compatibility in vehicle-to-vehicle crashes. Along with the need to protect the vehicle of a person driving in mixed traffic, it is also necessary to protect the other vehicle in an accident. This capability may be an important issue in the future. Among actual accidents, total fatalities are divided approximately evenly between single-vehicle accidents and vehicle-to-vehicle accidents. It is necessary to protect passengers in both of these types of accidents. In particular, during vehicle-to-vehicle collisions, it is necessary to consider the safety of the other driver -- not just the driver in the car which is being designed. Results from the vehicle-to-vehicle crashes of different weights specifically show this problem. Figure 9 illustrates this phenomenon graphically. As vehicle weight increases, the stiffness of the vehicle front increases.

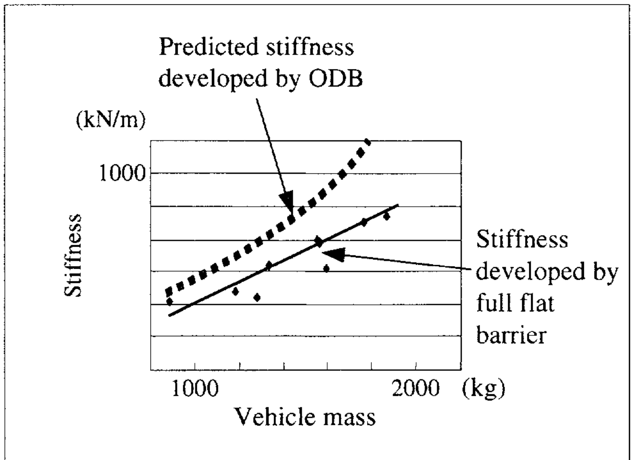


Figure 9. Prediction of stiffness

The test results done on each vehicle in the U.S. with an NCAP full frontal barrier show a strong correlation between vehicle weight and stiffness. In other words, an increase in vehicle weight can be inferred to lead to an increase in aggressiveness toward the other vehicle. As used here, the term 'vehicle stiffness' is defined as the slope of the load on the chassis as derived from an accelerometer attached to the cabin floor on the chassis. Figure 10.

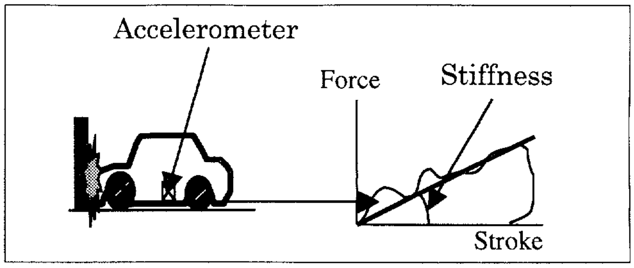


Figure 10. Definition of vehicle stiffness

Next we used same-weight vehicles as described above to verify the recent test method of the U.S. NHTSA, which is being researched based on vehicle-to-vehicle crashes. The 56km/h vehicle-to-vehicle crash results are shown in Figure 11.

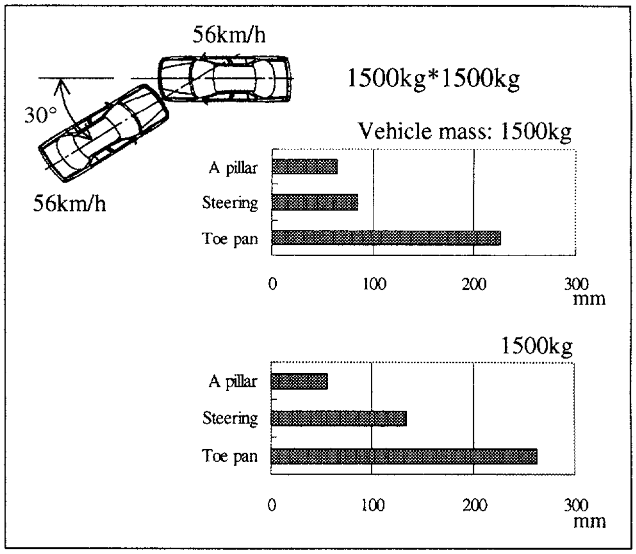


Figure 11. Vehicle deformation (vehicle-to-vehicle)

Figure 12 illustrates the results of a stationary vehicle crash test using a 112km/h moving deformable barrier (MDB).

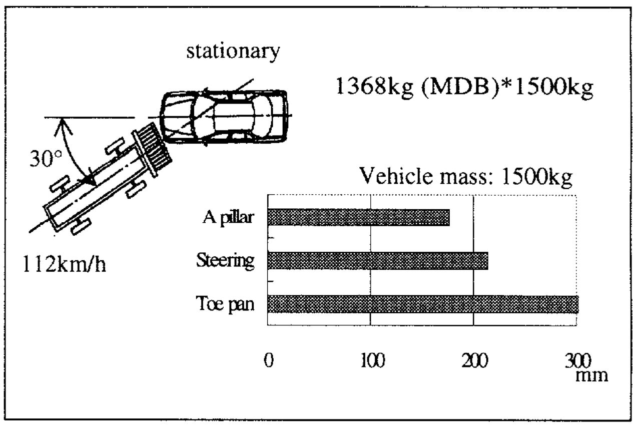


Figure 12. Vehicle deformation (vehicle-to-vehicle)

As indicated by the diagram, this test method clearly involves a vehicle-to-vehicle type of accident. One way it is different from the frontal offset crashes discussed thus far is that the offset is oblique. The second is to use an MDB. The MDB weighs 1368kg, which is the average vehicle weight in the U.S. This method appears to be based on the type of accident which is likely to occur frequently under actual road conditions. Note that the NHTSA research results should be checked for details regarding what types of actual accident situations are covered. As illustrated in Figures 11 and 12, a comparison of deformation amounts in the vehicle which is collided into shows that deformation for MDB and a vehicle is much greater than deformation between one vehicle and another.

One reason for this can be clarified by comparing the amount of deformation in the deformed area on the colliding vehicle. This comparison shows that there are problems in the characteristics of the barrier, i.e., the honeycomb, similar to the results for the offset deformable crash tests. As in the EEVC and IIHS tests, this problem seems to be due to honeycomb bottoming out, i.e., the stroke is significantly different than that of actual vehicles. Figure 13 illustrates the force (deceleration) vs. displacement characteristic in an actual vehicle compared to the results obtained in a test using a honeycomb.

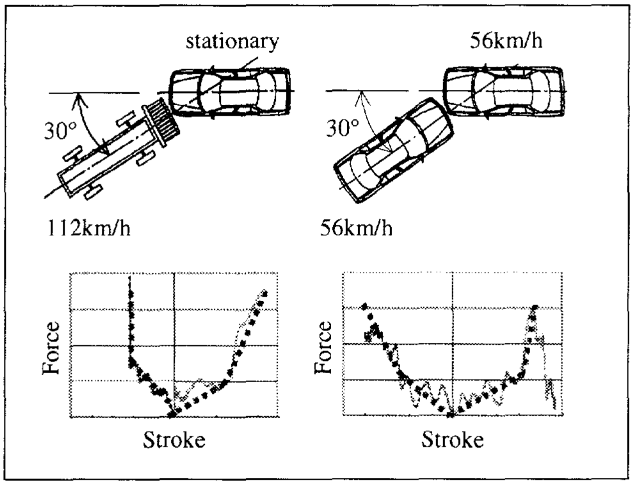


Figure 13. Comparison of Force-Stroke characteristics

Figure 13 also indicates a clear difference between the results. Assuming the collision speed simulation parameter is physically and theoretically correct, the honeycomb characteristics are a definite problem with this test method. This test method has other problems as well: reproducibility and practicality. Since this test method involves an oblique crash test, there is inconsistency in the amount of offset. And it is almost impossible to conduct the high MDB test speed in an ordinary indoor laboratory, so it is not well suited to third-party evaluation tests, including compliance. Then a test method which would theoretically solve the problems discussed above was devised. This test method, illustrated in Figure 14, was developed with consideration for reasonableness, faithfulness, reproducibility, practicality, and aggressiveness evaluations.

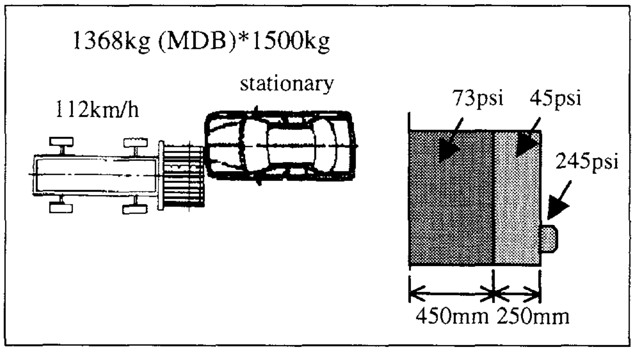


Figure 14. Test method of MDB-to-vehicle

Like NHTSA, for the MDB we selected the average weight which was most likely to be encountered under actual road conditions. We tried using a compound honeycomb consisting of a honeycomb which is average or has a hardness that is nearly the same as the stiffness of the engine rooms of vehicles which are commonly sold in the U.S., plus a honeycomb with stiffness characteristics similar to cabin stiffness. A relative MDB speed between 100km/h and 120km/h would simulate vehicle-to-vehicle collision speed of approximately 56km/h. In this test we used a speed of 112km/h. In order to minimize inconsistency in the data caused by the test method, we decided to make the collided vehicle stationary in a frontal offset collision. Some evaluations may consider an oblique collision to have a better correlation to actual road conditions, but oblique collisions were not used in this test. The test results are shown in Figure 15.

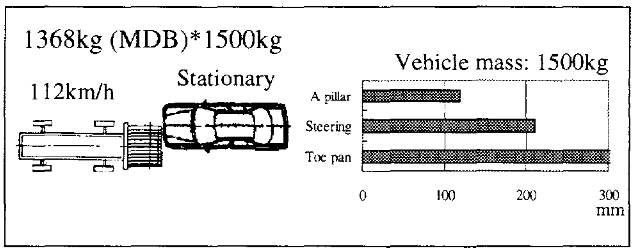


Figure 15. Vehicle deformation (MDB-to-vehicle)

The vehicle deformation approaches the test results in Figure 15, but the amount of deformation for the steering wheel is still larger. This seems to be due to the fact that the MDB rose onto the collided vehicle. There are two further problems with this test method. One is that it does not solve the difficulty of conducting the test in an ordinary indoor laboratory. The second problem is that the use of a compound honeycomb comprising two different honeycomb types makes it necessary to verify whether the method is acceptable in terms of production technology (including reproducibility), and whether the desired characteristics can be obtained.

CONCLUSION

The offset deformable barrier tests currently conducted using honeycombs are suitable for evaluating vehicle safety in vehicle-to-vehicle accidents involving vehicles which weigh approximately 1500kg or less. However, the results are not necessarily consistent with actual accidents in cases where the vehicles weigh more than approximately 1500kg. This is due to a problem with the specifications of the honeycomb, which is the deformable device. Specifically, the force-stroke characteristic of currently used honeycombs is not suitable for vehicle-to-vehicle crash tests with vehicle weights of 1500kg or greater. Our results reconfirm the recognition and observation by others that this is a bottoming out problem. In addition, it was learned that vehicle-to-vehicle offset collisions involving an MDB are not necessarily consistent with actual accidents in terms of what actually happens (e.g., the MDB rises onto the test car). Therefore further research is needed.

DISCUSSION

As described above, test methods involving deformable barriers have been proposed and are used to simulate vehicle to vehicle accidents. However, based on these tests results, the barrier characteristics do not always seem to replicate actual accidents. In cases where there is a difference in weight between vehicles, as is commonly found in vehicle-to-vehicle accidents, the heavier vehicle will suffer less deformation than the lighter vehicle. This has been confirmed experimentally, so test methods which provide different results are clearly problematic in a number of respects. Specifically, there is the problem of the collision speed, which is not related to the vehicle weights, and the related honeycomb characteristics. In the future we believe it will be necessary to establish appropriate test methods based on further research.

Another problem which may arise is that vehicles which are developed using such problematic test methods may not be suitable in terms of compatibility in vehicle to vehicle collisions -- an issue which is expected to be important in the future. In particular, heavier than average vehicles which are sold in each market have the potential to increase aggressiveness toward small and lighter-weight vehicles.

This paper presents research on vehicle to vehicle tests involving an MDB, and compares these tests to ODB crash tests which are currently used. Further research will be needed in the future on criteria for evaluating vehicle aggressiveness.

Collision accidents are extremely complex. For this reason, it is necessary to have a number of methods for evaluating crashworthiness -- not just one method. In particular, it is impossible to use a single test method to evaluate mutually contradictory phenomena (i.e., single vehicle crash protection evaluations and securing cabin space in vehicle-to-vehicle crashes). Therefore, care must be taken in publishing test results supposedly serving as safety information.

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