INNOVATIVE BODY STRUCTURE FOR THE SELF-PROTECTION OF A SMALL CAR IN A FRONTAL VEHICLE-TO-VEHICLE CRASH

Masuhiro Saito
Tetsuya Gomi
Yoshinori Taguchi
Takeshi Yoshimoto
Tomiji Sugimoto
Honda R&D Co., Ltd. Tochigi R&D Center
Japan
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ABSTRACT

Preservation of passenger compartment space during a frontal vehicle-to-vehicle collision is extremely significant for the self-protection of small cars.

It is well known that crash speed, mass, stiffness and geometric interaction all have an influence on the intrusion of the passenger compartment in a frontal impact between vehicles. This paper reports on a new enhanced body structure to reduce passenger compartment intrusion in a crash between large and small cars. The test discussed in this report set the crash speed of both cars at 50kph, the mass of the large car at almost twice that of the small car, and the small car over lap at 50%. The proposed innovative body structure for the front end of small cars achieved a previously unavailable level of efficiency of energy absorption and was able to maintain cabin integrity.

INTRODUCTION

In recent years the use of stationary barrier crash tests as a method of evaluation of crash safety performance has increased internationally. This has been very effective in improving vehicle crash safety performance and reducing the number of casualties in traffic accidents.

However, in the case of frontal collisions between small cars and large cars in the real world accident, it is said that the risk of injury to the small car's occupants is higher than that to occupants of the large car. This is caused by incompatibility between 'mass' 'stiffness' and 'geometry' in vehicle-to-vehicle collisions. A collision in which the mass and stiffness ratios of the vehicles are large is equivalent to an extremely high speed stationary barrier crash for a small car.

Small cars which receive good evaluations in full lap and offset frontal crash barrier tests are therefore not always sufficiently safe in a small car to large car collision in the real world accident. And it begins to be pointed out the necessity to have an another manner to evaluate it in the collisions with relatively different sized vehicles.

In particular in the case of narrow offset collisions in which overlap distance is relatively small in the direction of the vehicle's width and collisions with differing bumper height, it is very difficult for conventional body structures to maintain crash safety performance. It is therefore necessary to propose innovative body structures based on new design concepts. Of course it goes without saying that it is extremely significant for compatibility not only to consider the progress of self-protection but also partner-protection (for opposite vehicles). This research reports on the possibility to improve the self and partner protection which are discussed in the society by modifying the body structure such as one of the unique technique.

THE SAFETY IMPROVEMENT FOR SMALL CARS

In frontal vehicle-to-vehicle collisions it has been discussed that mainly 'mass' 'stiffness' and 'geometry' are the factors for incompatibility. In this part we report on some subjects and solutions in the view of the self-protection for small cars.

The portion of the velocity change before and after collisions is influenced by mass ratio as follows.

$$Vr = 1/Mr \qquad (1.)$$

$Vr = \Delta V_2 / \Delta V_1$ ΔV_i: velocity change of Vehicle i $Mr = M_2/M_1$ M_i: mass of Vehicle i

The lighter vehicles are forced to a higher deceleration level than the heavier vehicles. As a result the risk of injuries in small cars is higher than in large cars. We will be able to solve such mass incompatibility developing superior restraint systems for small cars and to reduce mass in large cars.

The portion of energy absorption in vehicle deformation depends on stiffness ratio of two vehicles as follows.

$$Er = 1/Kr \qquad (2.)$$

$Er = E_2/E_1$ E_i: energy absorption of Vehicle i
$Kr = K_2/K_1$ K_i: stiffness of vehicle i

The problem is how to balance several vehicles' stiffness. To be realistic we need to improve the stiffness for small cars.

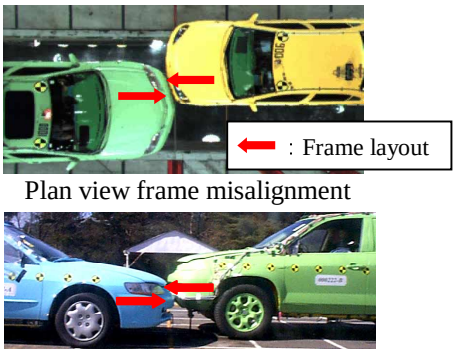
Certainly as stated above the difference between mass and stiffness is a problem for the compatibility, however we should first improve geometrical compatibility.

In recently years the level of self-protection for small cars has advanced greatly because of the adoption of offset deformable barrier testing. However the deformable barrier is very uniform in stiffness. But in reality, the front of vehicle in vehicle-to-vehicle collisions lack uniform stiffness, which causes severe damage to small cars. After this we focus on the improvement of interaction in frontal structures.

NEW DESIGN CONCEPT

To improve the offset and full lap frontal crash performance, conventional body structures are generally designed with two main frames located on each side of the engine compartment to absorb vehicle energy and to control vehicle deceleration.

However, in the case of vehicle-to-vehicle collisions such as narrow offset collisions in which there is less overlap distance in the direction of vehicle width and collisions between a passenger cars and a Sports Utility Vehicle (SUV) in which the bumper beam heights of the vehicles differ (as shown in Figure 1), this body type allows structural penetration into the engine compartment.



Plan view frame misalignment

Side view frame misalignment

Figure 1. Misalignment of stiffness between vehicles in vehicle-to-vehicle collision.

In particular when there is a significant difference in vehicle weight, the bumper beam and main frame of the large car passes into the frame of the small car without sufficient energy absorption and deceleration, penetrating the weaker part of the small car. As a result, deformation extends to the small car's passenger compartment, increasing injuries to occupants from secondary collisions in the passenger compartment, as shown in Figure 2.

It is important for the improvement of the level of protection offered by small cars to prevent structural penetration of major frontal components, increase the homogeneity of strength distribution and improve energy absorption in the engine compartment in the event of vehicle-to-vehicle collisions between vehicles with misalignment of stiffness. The design concept will be expected not only to achieve progress for self-protection but also the effect of partner-protection for compatibility.

Figure 2. Large deformation of the passenger compartment after narrow offset vehicle-to-vehicle collision.

STRUCTURAL OUTLINE AND CRASH PERFORMANCE

The proposed structure consists of three components, as shown in Figure 3.

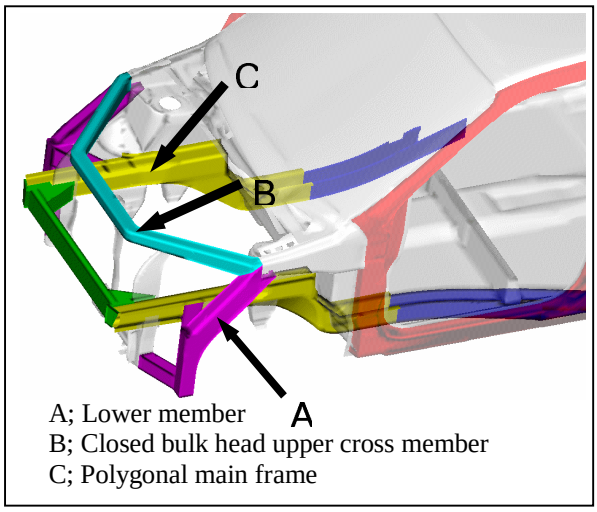


Figure 3. Structural outline.

These components are A; A lower member to prevent penetration. B; A closed bulk head upper cross member to assist energy absorption in the upper part of the engine compartment. and C; A polygonal main frame enabling high efficiency energy absorption. This paper will offer a structural outline of the lower member system and discuss the predicted effectiveness of this system as determined by computer simulations.

The new 'lower member' was positioned in front of the tires extending from the wheel house upper member, and was connected to the main frame and bulk head cross member. This prevents the penetration of the frames of the respective vehicles in narrow offset collisions and collisions between vehicles with differing bumper heights. (See Figure 4). On impact, the lower member makes contact with the front structure of the other vehicle and deforms, thus achieving a high level of energy absorption (as shown in Figure 5).

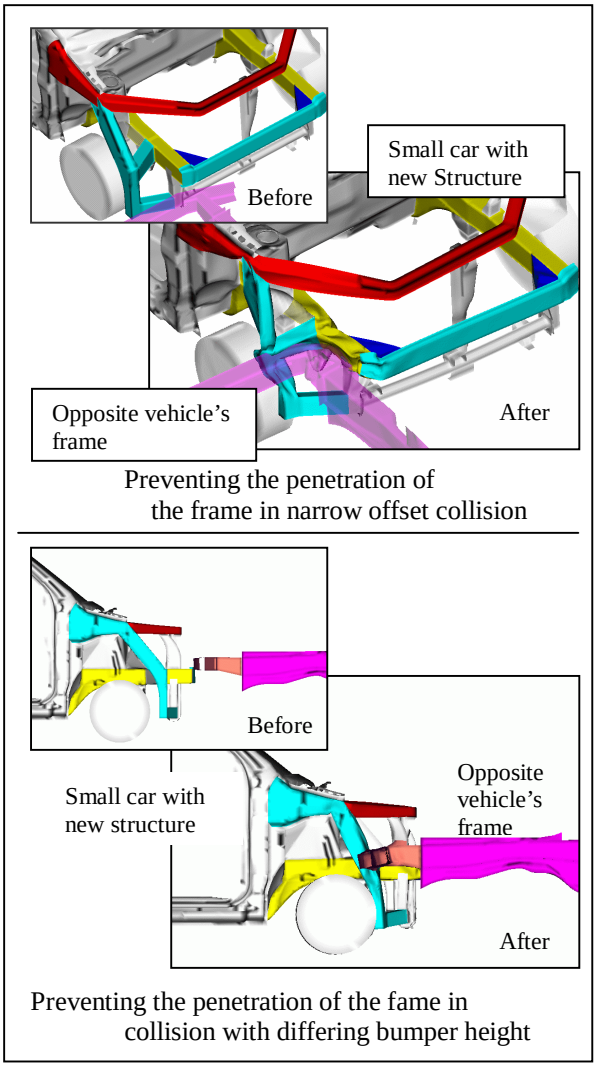


Figure 4. Preventing the penetration of the Frame.

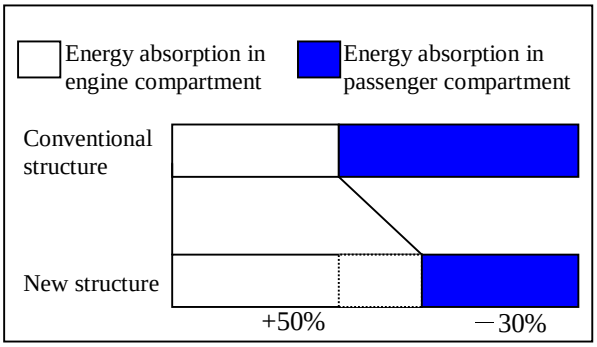


Figure 5. Increasing energy absorption in the engine compartment from vehicle-to-vehicle collision.

This leads to a significant reduction in the proportion of energy absorption in the cabin and of the degree of passenger compartment intrusion. The effectiveness of the new structure in reducing passenger compartment intrusion is shown in Figure 6.

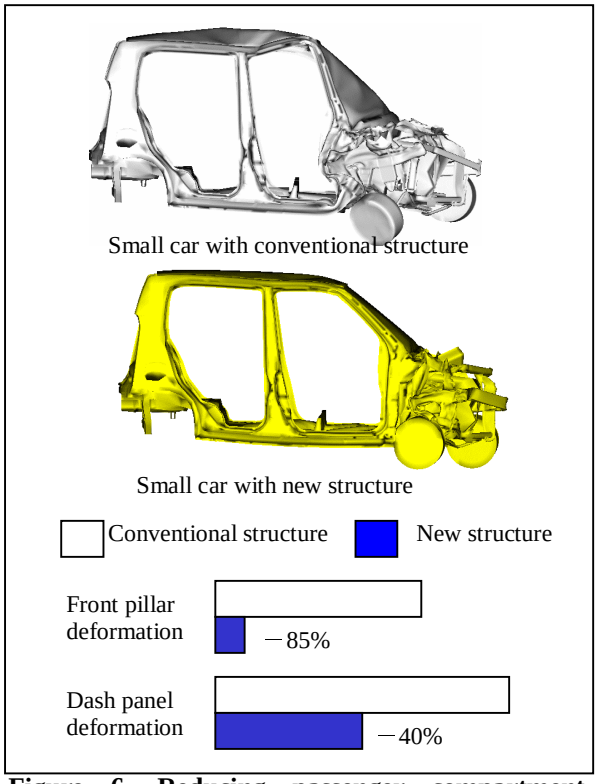


Figure 6. Reducing passenger compartment intrusion in vehicle-to-vehicle collision.

The new structure also enables reduction of the strength and weight of the main frame, allowing a more homogeneous distribution of strength in the front end structure.

It is predicted that this structure will be effective in reducing passenger compartment intrusion for various overlap distances in the direction of vehicle width (as shown in Figure 7), for the difference of bumper height (as shown in Figure 8) and for angle of approach (as shown in Figure 9).

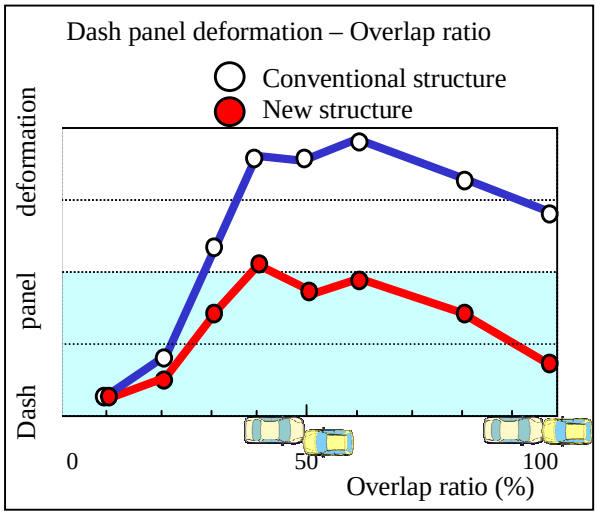


Figure 7. Reducing passenger compartment intrusion in various offset vehicle-to-vehicle collisions.

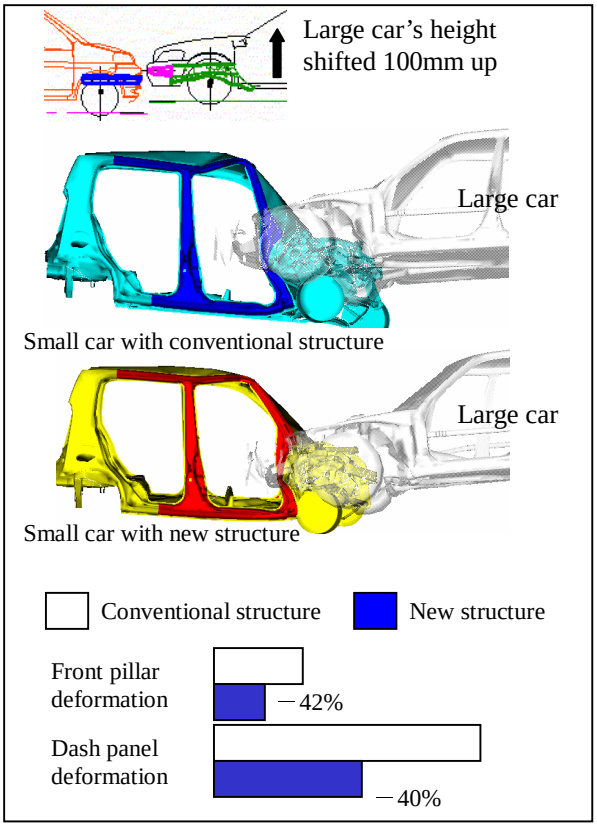


Figure 8. Reducing passenger compartment intrusion for vehicle-to-vehicle collisions with differing bumper height.

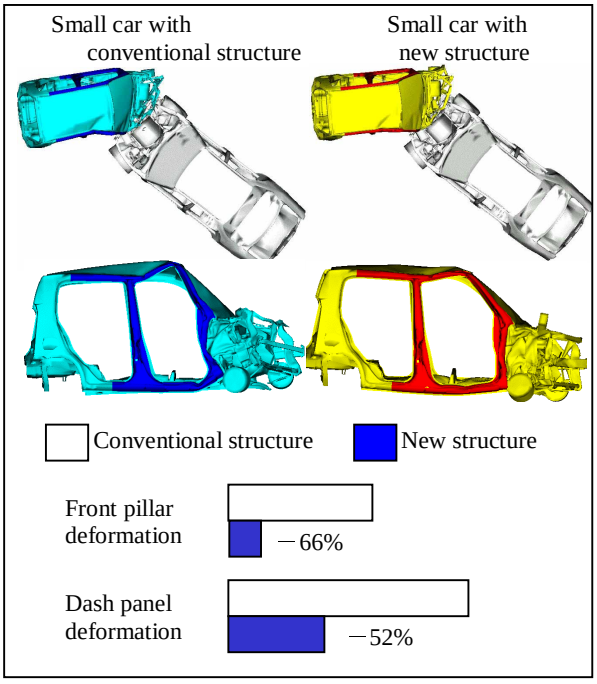


Figure 9. Reducing passenger compartment intrusion for angle of approach in vehicle-to-vehicle collision.

AGGRESSIVENESS

Secondly we give consideration to aggressiveness. As a result of above-mentioned vehicle-to-vehicle simulations, energy absorption in the engine compartment has increased slightly and the energy absorption in the cabin is decreased in large cars with conventional body structures by means of the effect from the new structure. It can therefore be predicted that the new body structure will not increase aggressiveness towards the partner vehicle in a collision (as shown in Figure 10).

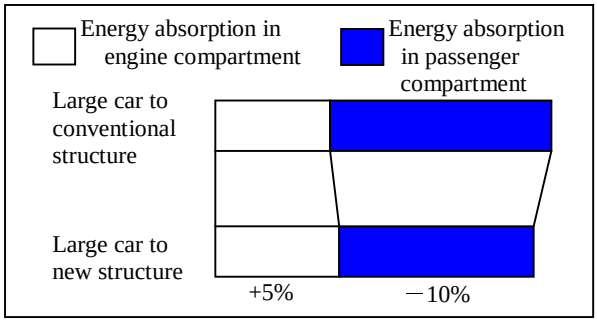


Figure 10. Improving of energy absorption.

Further we analyzed aggressiveness towards small cars as follows. We describe the simulation results in a frontal collision between similar small cars A and B with conventional structure (case 1), and between a small car A with conventional structure and a small car C with the new proposed structure (case 2)in Figure 11. Opposite car's intrusion in the passenger compartment was approximately similar in both cases. We could assess that our proposed new structure greatly improved self-protection, and doesn't increase the aggressiveness towards the small car, and we could find the possibility for compatibility.

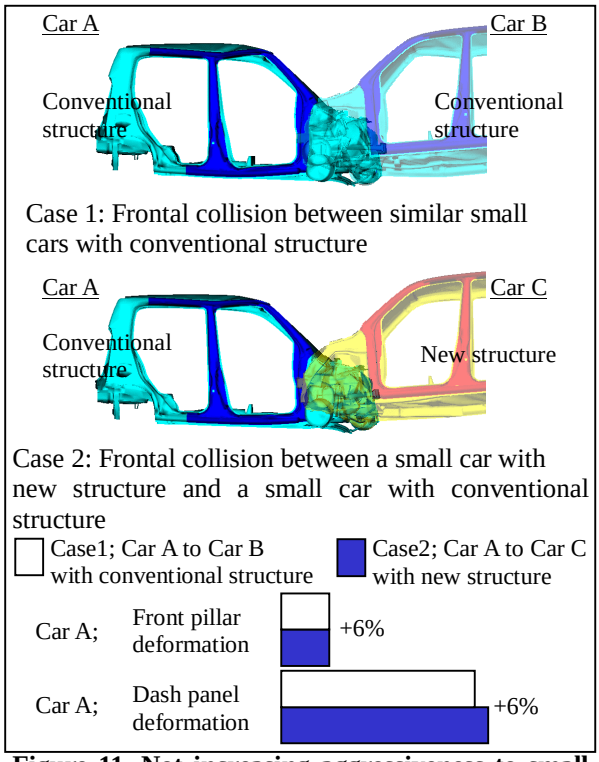


Figure 11. Not increasing aggressiveness to small cars.

ACCIDENT ANALYSIS

This time the condition in a vehicle-to-vehicle crash test was based on the accident analysis in Japan. Some accident data were provided from the Institute for Traffic Accident Research and Data Analysis (ITARDA) established in 1992.

Almost half of the number of occupant deaths is in the case of frontal collisions as shown in Figure 12[1]. About 90% of the frontal collision deaths were at speeds lower than 50kph as shown in Figure 13 [1]. And when the opposite vehicles are heavier than the subject vehicles, the driver deaths in frontal collisions are about 75% as shown in Figure 14 [1]. With relation to overlap in frontal collisions, 30% and 50% overlap cases are the primary overlap conditions for offset collisions (as shown in Figure 15) [1].

For reduction casualties, we would get effective test results from test condition based on accidents analysis.

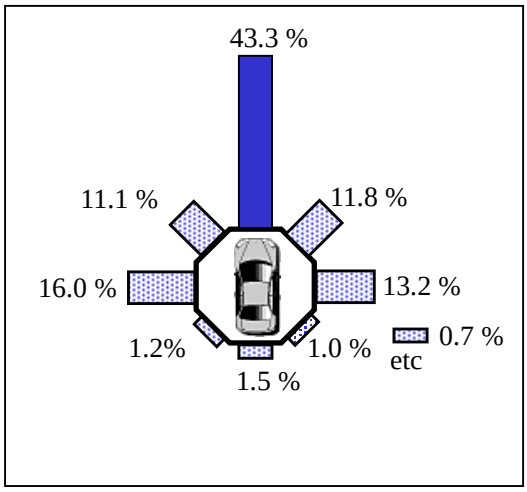


Figure 12. The collision direction in the fatal accidents for vehicle-to-vehicle collisions.

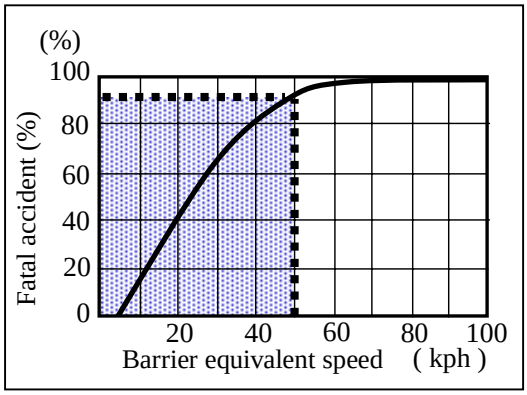


Figure 13. Fatal accident speed and percentage in frontal collisions.

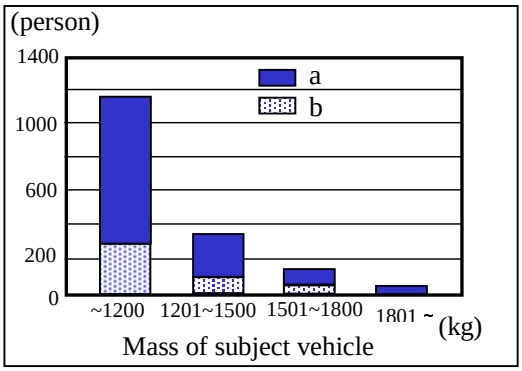


Figure 14. Vehicle mass and the driver fatalities of subject vehicle in frontal collisions.
; a) The opposite vehicle is heavier than the subject vehicle.
; b) The opposite vehicle is lighter than the subject vehicle.

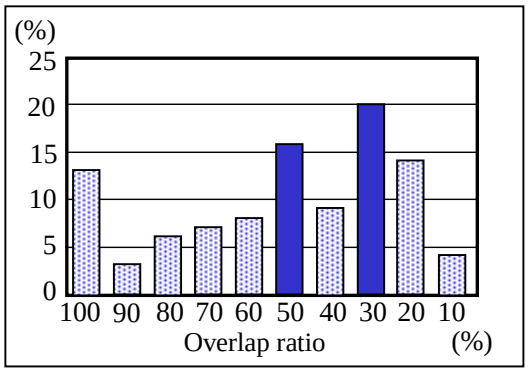


Figure 15. Overlap ratio in frontal collisions.

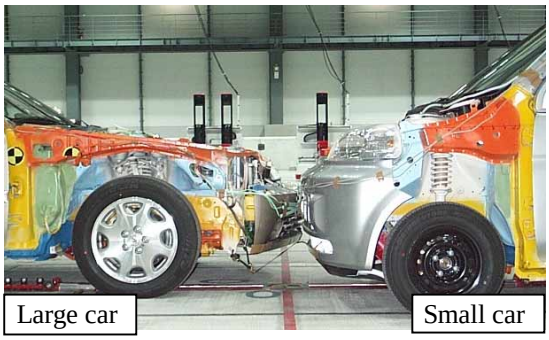
TEST CONDITIONS

The target in this test is the verification for a small car's self-protection in the conditions based on real world accidents, especially the improvement of geometrical interaction in the frontal structure.

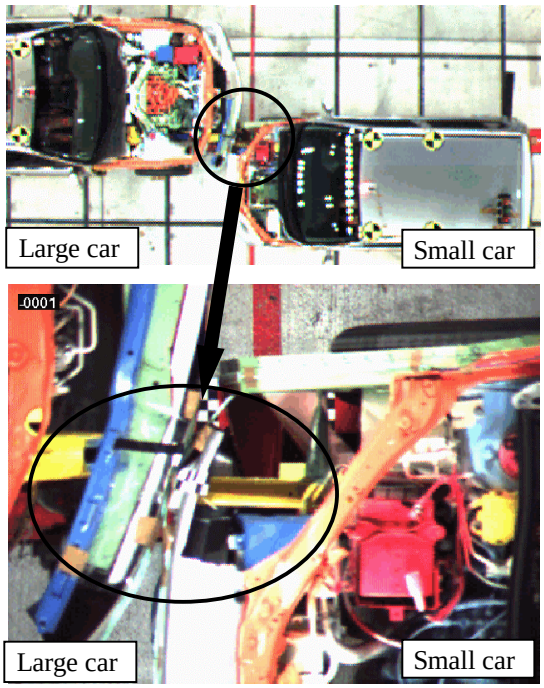
Small car: Prototype model
(This time only the 'Lower member system' was added on.)
Large car: Conventional model
Speed: 50kph per car
Mass : Small car 985kg Large car 1855kg
Mass ratio: 1.9 (Large car／Small car)
Overlap ratio: 50% of small car

The 50% overlap case is the reason that the risk of injury is higher than 30%. (as shown in figure 7)
Impact angle is 0°to the car's longitudinal axis.
Figure 16 shows the two cars before the crash test.
The main structural layouts of the cars are shown in Figures 17.

Figure 16. Two cars before the crash test.



Bumper heights are approximately the same.



The main frame of the vehicles did not overlap in the direction of width.

Figure 17. Main structural layout of two cars.

In this test the main frames of the cars did not overlap in the direction of the cars' width, and the bumper heights were approximately the same.

Dummy: HybridⅢ

Restraint system: airbag and seat belt pretensioner with load limiter.

The restraint specification is similar to a small car without suitable modification for the change of the vehicle's deceleration characteristic.

TEST RESULTS

Speed: Small car 50.0kph
Large car 49.9kph
Overlap ratio: 48% of Small car

Figure 18 shows two cars after the crash test.

The structural deformation of the small car and the large car is shown in Figures 19 and 20 respectively.

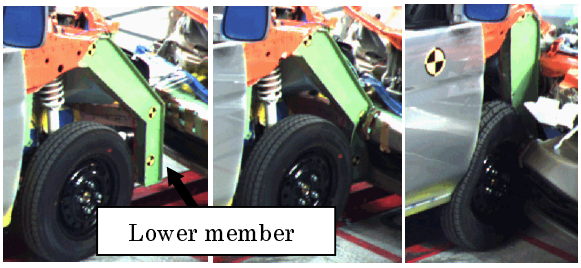
The mode of structural deformation in the engine compartment of the small car during the crash is shown in Figure 21. Figure 22 shows deformation in the engine compartment of the small car after the crash.

Each part of deformation in both cars is listed in Table 1. Figure 23 shows the velocity change of both cars.

Figure 18. Two cars after the crash.

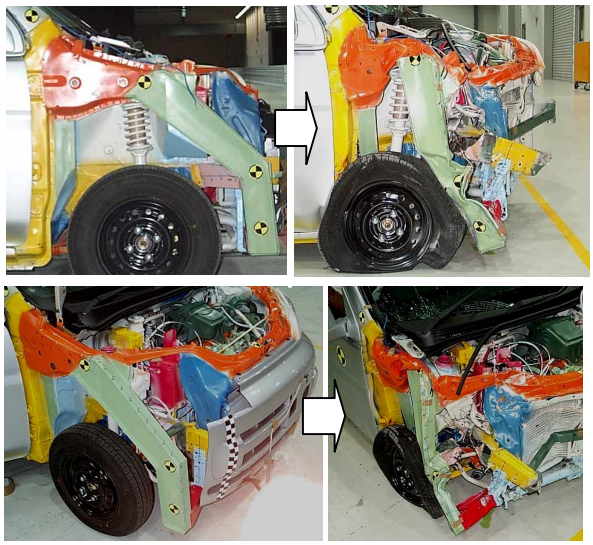
Figure 19. Deformation of small car with the new structure after the crash.

Figure 20. Deformation of large car after the crash.



0msec 10msec 38msec

Figure 21. Deformation mode of small car's new structure during the crash.



Before the crash After the crash

Figure 22. Deformation of small car in the engine compartment after the crash.

Table 1. Deformation

		Small car with new structure	Large car
Deformation	Front pillar(mm)	13	9
	Dash panel(mm)	114	162

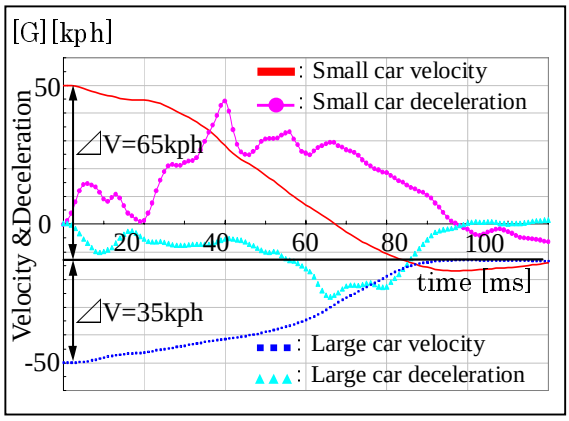


Figure 23. Velocity & Deceleration of both cars.

The vehicle-to-vehicle crash test confirmed the effectiveness of the new design in increasing the level of self-protection of small cars. The mode of deformation on impact confirmed that the bumper beam and main frame of the large car collided with the new lower member fitted in the small car.

The lower member restrained intrusion into the small car by making contact with the tire and wheel. Intrusion of the passenger compartment was therefore significantly reduced and the integrity of the cabin was maintained for occupants. The large car deformations in each part were approximately similar with the small car deformations.

The risk of injury to the small car's occupants were generally low by the prevention of secondary collisions in the passenger compartment.

The test results show the small car driver's injury risk is higher than the large car driver's injury risk. The reason is that the small car's Δ V[65kph], (namely the velocity change of before and after impact) is higher than the large car's Δ V[35kph], due to the influence by mass ratio.

CONCLUSION

A small car to large car crash test confirmed that the new body structure is one of the ways in increasing the level of self-protection of small cars.

It is very difficult for small vehicles with conventional body designs to maintain cabin integrity in narrow offset collisions and collisions with SUV because of the intrusion of the frame of the other vehicle

The innovative body structure proposed in this research reduces passenger compartment intrusion and occupant injury by restraining frame intrusion and enabling a high level of energy absorption in the engine compartment.

The structure improves the level of self-protection in small cars, it is also expected to improve the level of partner-protection offered by large car. As a further step we are going to research the aggressiveness for large cars based on the proposed new structure in this report.

Therefore, new design concept in making vehicles isn't an individualistic one and doesn't aim for only superior self-protection. Rather, the concept is harmony with the society of automobiles.

Finally it is hoped that the proposal of this new structure will trigger further research on body structures enabling reduction of traffic accident casualties in the future.

REFERENCES

[1] The Annual Reports of Traffic Accident Research and Data Analysis.1996.ITARDA.