VEHICLE FRONT STRUCTURE IN CONSIDERATION OF COMPATIBILITY

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ABSTRACT

A structure which effectively improves compatibility in a vehicle-to-vehicle frontal impact has been considered focusing on sub-frame structure that disperses applied force with multiple load paths. Evolved sub-frame structure has been studied by CAE with RADIOSS to search the possibility to reduce aggressivity and to improve self-protection at the same time.

Vehicle models used for this compatibility study were a large saloon car with sub-frame and a small family car without sub-frame. The large saloon car had three different front structures: original, forward-extended sub-frame, and original with 25%-stiffness reduced structures. The types of collision contained four different crash modes in a combination of lateral overlap rate difference and side member height difference. With these three different structures in four different crash modes, crash simulations were conducted to evaluate aggressivity and self-protection based on front structure and compartment deformations, energy absorption amount, and Average Height of Force (AHOF).

As a result, it was found that the front structure with forward-extended sub-frame improved both aggressivity and self-protection by preventing override effect through structural interaction enhancement.

INTRODUCTION

In the United States, with the growing popularity of light trucks and vans (LTVs), the aggressivity of LTVs as an issue of concern is growing. According to field data analysis by NHTSA based on Fatality Analysis Reporting System (FARS) data, driver fatality ratio in frontal-frontal LTV-to-passenger car crashes ranges from 1:2.6 to 1:6.2 [1]. The aggressivity of LTVs is obvious and undeniable. Highly possible factor of aggressivity is geometric difference, in particular, height differences of structural stiff parts like side members.

Recent studies on crash compatibility between vehicles have shown that the factors influencing crash compatibility performance are vehicle mass, stiffness, and geometry. The majority of the studies has concluded that geometry is the most dominant factor [2, 3, 4, 5, 6, 7, 8]. And of the geometric incompatibilities, height difference of stiff structural parts is a major concern. Height difference of structural parts leads to override and/or underrun effects, where energy absorption efficiency of both vehicles is impaired, generating additional compartment intrusion. When a vehicle is overridden, the crash energy is absorbed only by the upper body, generating a significant upper body intrusion in cowl and instrument panel areas of the overridden car compartment [4, 6, 8], compounding injury and fatality risks to the occupants.

For compatibility improvement, structural interaction to minimize override potential and effect, therefore, is most important. Thus, this study attempts to reduce aggressivity and to enhance self-protection by controlling override effect through structural interaction enhancement.

VEHICLE-TO-VEHICLE FINITE ELEMENT SIMULATIONS

Crash Models

Vehicle-to-vehicle frontal crash simulations were conducted by FEM to isolate and identify the vehicle structures that contribute to improvement of compatibility performance. Vehicle models used for the study were a large saloon car with sub-frame shown in Figure 1 and a small family car without sub-frame in Figure 2. These models were highly correlated with rigid barrier frontal impact. The large saloon car had three different types of frontal geometry:

- Original structure, a base structure (hereinafter described as "original type")
- Forward-extended sub-frame structure for override prevention shown in Figure 3 ("extension type")
- Original structure with 25%-stiffness reduced by side member and sub-frame material thickness reduction ("low stiffness type")

The weight of large saloon car, 1,326kg, was equalized to that of small family car so that weight factor in this study can be eliminated. This is the average weight of passenger cars in Japan: 1,150kg plus two Hybrid III 50th percentile male dummies. Initial crash velocity of both vehicles is also the same, 56km/h.

Table 1 summarizes vehicle model characteristics of large saloon and small family cars. RADIOSS software was used to make calculations during the period of first 150ms after the collision.

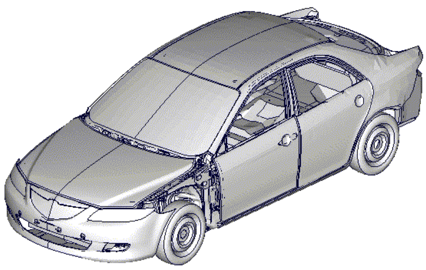

Figure 1. FEM model of large saloon car with sub-frame.

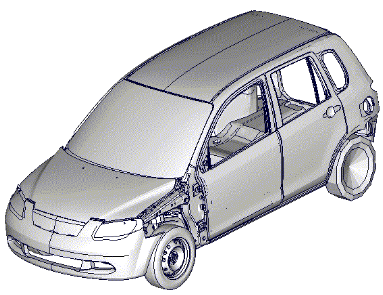

Figure 2. FEM model of small family car without sub-frame.

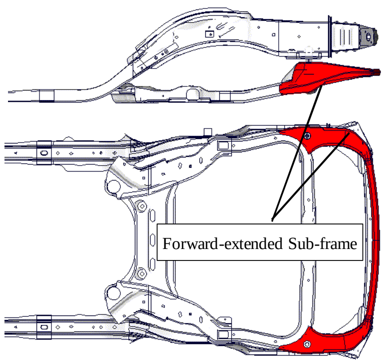

Figure 3. Forward-extended sub-frame structure of large saloon car.

Table 1.
FEM model characteristics

	Large saloon car			Small family car
	Original type	Extension type	Low stiffness type	
Nodes	265,000	267,000	265,000	231,000
Elements	270,000	273,000	270,000	261,000
Length	4,670 mm			3,925 mm
Width	1,780 mm			1,680 mm
Mass	1,326 kg			1,326 kg

Simulation Matrix

There were four vehicle-to-vehicle frontal crash modes. Figures 4 and 5 depict two different lateral lap amounts, 50% and 100%, and two different height differences, 0mm and 100mm, respectively. In the case of 100mm-height difference, the side member of the large saloon car is higher than that of the small family car. Combinations of these overlap amounts and height differences were adopted as crash modes. The simulation test matrix contains 12 cases shown in Table 2, combining these four test modes and three different vehicle front geometries of the large saloon car.

Under the combination, toeboard and A-pillar intrusions on driver side on both models were measured to evaluate compatibility performance.

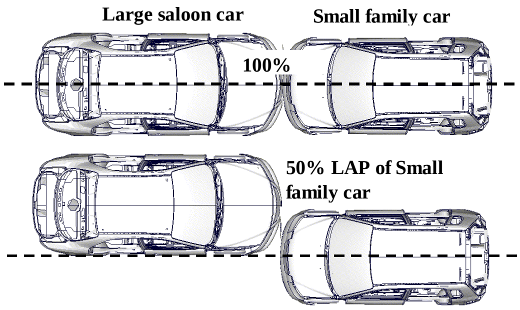

Figure 4. Lateral overlap.

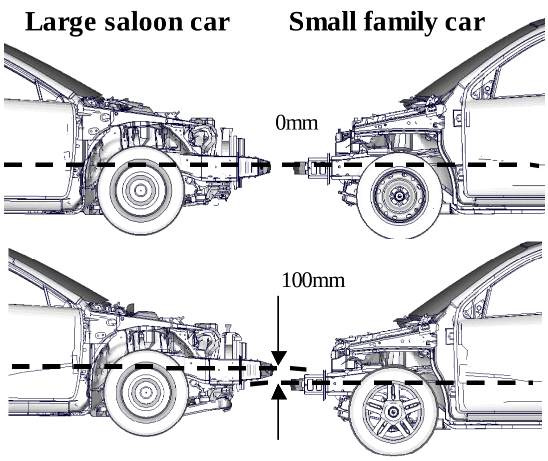

Figure 5. Side member relative height difference.

Table 2. Simulation matrix

Crash mode		Front end structure	
Lateral lap	Side member height of large saloon car in comparison with small family car	Large saloon car	Small family car
100%	0mm	Original	Original
		Extension	
		Low stiffness	
100%	100mm	Original	Original
		Extension	
		Low stiffness	
50%	0mm	Original	Original
		Extension	
		Low stiffness	
50%	100mm	Original	Original
		Extension	
		Low stiffness	

RESULTS AND DISCUSSION

Front Structure Deformation

This section describes vehicle behavior varied by difference in vehicle structure and crash modes. Figures 6 through 9 illustrate deformation modes of original and extension types of large saloon cars and small family cars at 40ms with 100mm-height difference. The greatest difference in deformation mode appeared at 40ms and no outstanding mode change was seen after 40ms. Therefore, deformations at 40ms were evaluated. Figure 6 shows original type with 100% lateral lap, and Figure 7, extension type. Figure 8 exhibits original type with 50% lateral lap, and Figure 9, extension type. Figures 8 and 9 depict right side members. The results show a conspicuous structural interaction difference between original and extension types. In the case of original type in Figure 6, the side member of the large saloon car overrode that of the small family car. This left some portion of the small family car's side member undeformed. Meanwhile, in the case of extension type in Figure 7, the side member of the small family car was sandwiched between the extended sub-frame and side member of the large saloon, preventing the small family car from underrunning the large saloon. Further, the frontal area of the small family side member also deformed, proving that there had been good interaction. Similar results were seen in the 50% lateral lap as shown in Figures 8 and 9. However, no difference was seen in the vehicle movement between low stiffness and original types. Thus, it follows that the extension type can prevent the opponent vehicle from underrunning by improving interaction even when the side member height is different.

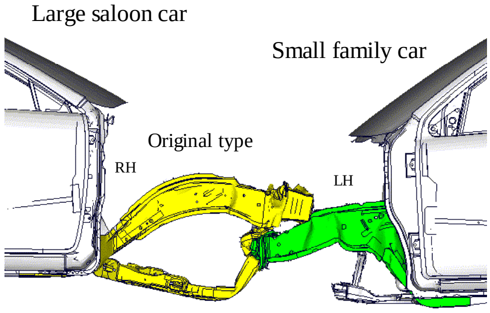

Figure 6. Deformation mode in 100%-lap - original type.

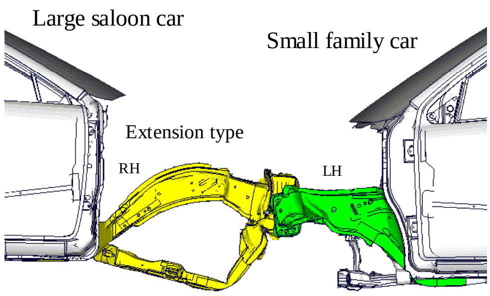

Figure 7. Deformation mode in 100%-lap - extension type.

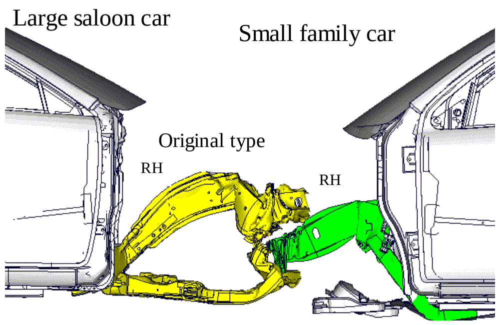

Figure 8. Deformation mode in 50%-lap - original type.

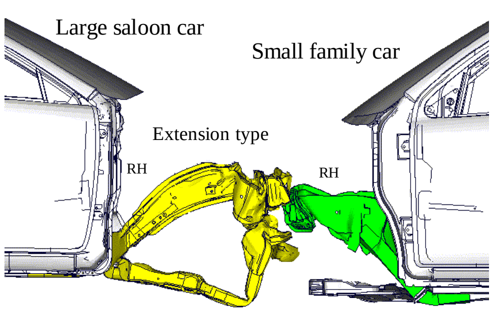

Figure 9. Deformation mode in 50%-lap - extension type.

A comparison of side member and sub-frame deformation was made quantitatively, and the characteristics of extension type were investigated. Figure 10 indicates measuring points on the front areas of the large saloon and the small family cars. Note that the front end of the extended sub-frame was not measured and therefore not illustrated for the extension type. Connecting lines are drawn between these points, and from a side view of the lines were made the comparisons.

Figures 11 through 14 show deformation modes of original and extension types of large saloon cars and small family cars at 40ms. These figures reveal two notable deformation features when the extension type of large saloon car is collided with the small family car. One is that the sub-frame of the extension type bends downward at the center more stably compared with the original type. The bending points are marked with “A” in Figures 10 through 14. The other feature is that the extended sub-frame holds and deforms the side member of the small family car, preventing the small family car from underrunning as marked with circles in Figures 12 and 14. The deformation of the side member of the small family car contributes to the smaller deformation of its compartment.

As far as low stiffness type is concerned, it did not show any improvement in interaction as illustrated in Figure 15.

The extension type of large saloon car has the following features:

- It stabilizes deformation mode of its own side member and side frame.
- It prevents the small family car from underrunning.
- It deforms the side member of small family car effectively.

The extended sub-frame has the potential to reduce aggressivity by improving structural interaction, especially when there is geometric incompatibility between two vehicles.

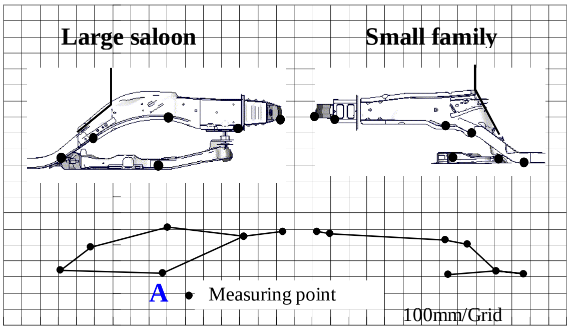

Figure 10. Measuring points for deformation mode comparison.

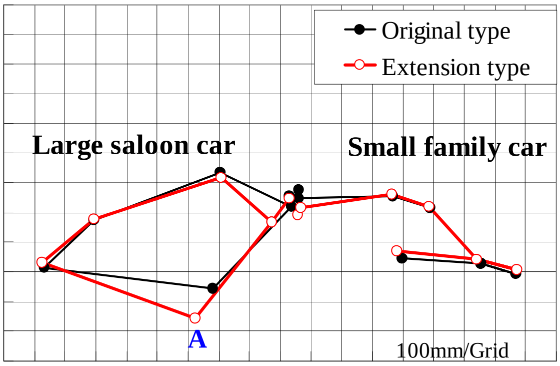

Figure 11. Deformation comparison between original and extension types in 100%-lap and 0mm-height difference.

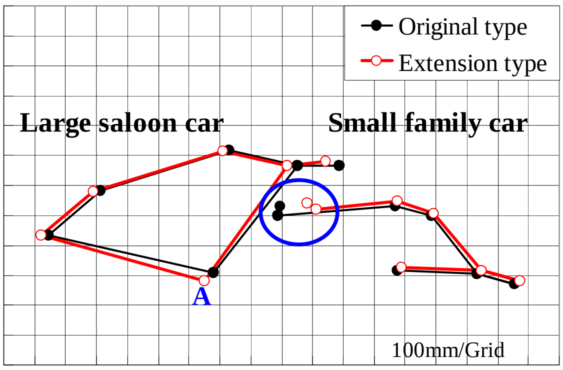

Figure 12. Deformation comparison between original and extension types in 100%-lap and 100mm-height difference.

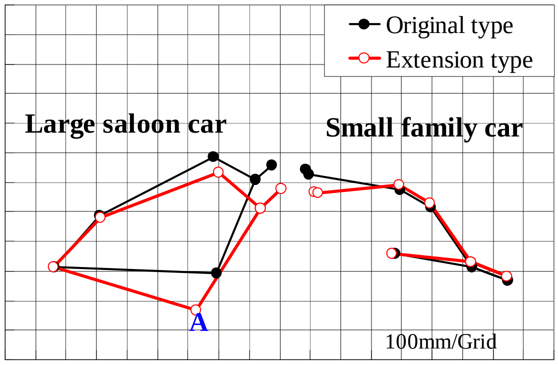

Figure 13. Deformation comparison between original and extension types in 50%-lap and 0mm-height difference.

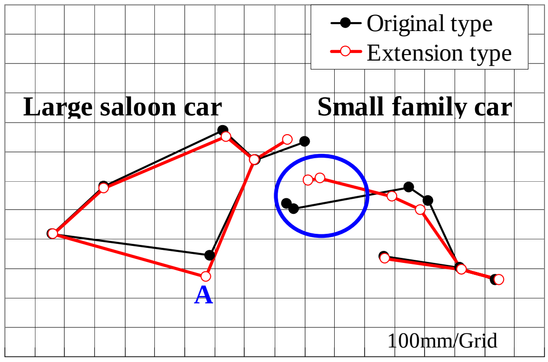

Figure 14. Deformation comparison between original and extension types in 50%-lap and 100mm-height difference.

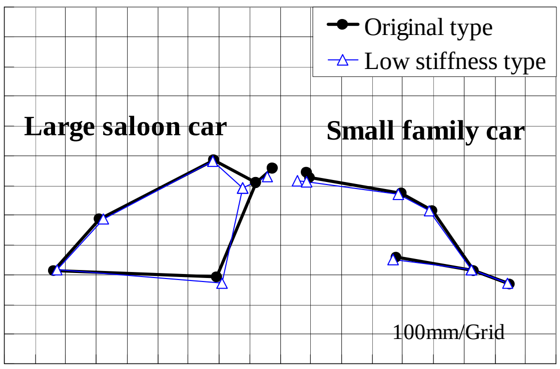

Figure 15. Deformation comparison between original and low stiffness types in 50%-lap and 0mm-height difference.

Compartment Deformation

Vehicle deformation amount was compared to evaluate compatibility performance. For the compatibility evaluation, toeboard and A-pillar intrusions were chosen to measure the damage on compartment. The large saloon car was defined as subjective vehicle and the small family car as opponent vehicle. When the intrusion amount of the large saloon car was smaller than that of original type of the large saloon car, it was judged as effective for self-protection. And if the intrusion amount of the small family car was smaller than that of the small family car collided with original type, it was judged as effective for aggressivity reduction.

Figure 16 shows the toeboard intrusion on driver side. With regard to the extension type, toeboard intrusions of both the large saloon and small family cars are reduced compared to the original type in every crash mode. Figure 17 shows A-pillar intrusion on the driver side. Since the A-pillar intrusion of the large saloon was too small, we only evaluated intrusion of the small family car. In the case of extension type, A-pillar intrusion of the small family car was reduced compared to the original type in every crash mode. Therefore, it follows that the extension type can reduce toe-board and A-pillar intrusions for both vehicles.

This means that the extension type improved self-protection and reduced aggressivity at the same time. As mentioned earlier, this is because the extension type has the possibility of improving interaction and it deforms the front area of both vehicles efficiently.

For the low stiffness type, intrusion amounts of toeboard and A-pillar are not necessarily smaller than that of the original type. It is theoretically considered that reduced stiffness should increase the deformation amount of its own vehicle. However, because the geometry influence is so dominant in a vehicle-to-vehicle crash, stiffness reduction effect was not observed as expected.

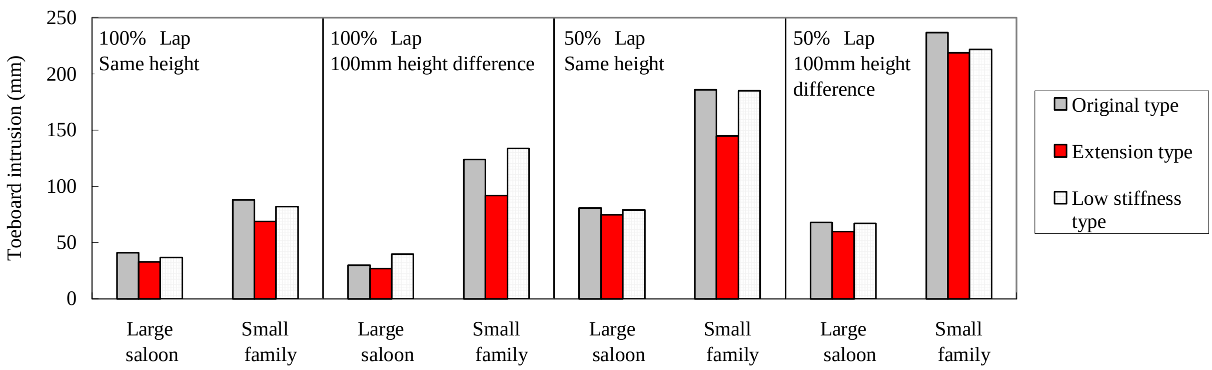

Figure 16. Comparison of toeboard intrusion.

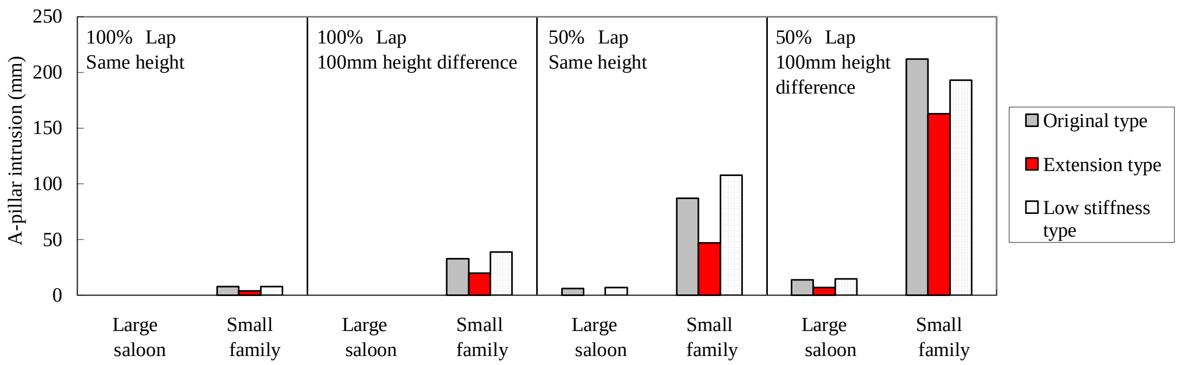

Figure 17. Comparison of A-pillar intrusion.

Energy Absorption

From standpoints of deformation on front structure and compartment, compatibility was so far investigated. The results show that the extension type has the possibility of improving aggressivity and self-protection. In this section, compatibility is discussed in terms of energy absorption. The energy absorption amount means a total value of energy absorbed by every component of a vehicle model calculated by computer simulation. Figure 18 shows energy absorption share of large saloon car. To calculate the energy share, the energies absorbed by the large saloon car and by the small family car were added. The total energy absorbed by both vehicles was always reserved as 100%.
Compared to the original type, the extension type of large saloon car increases its own energy absorption share and decreases the energy absorption share of the opponent small family car, which is good for aggressivity reduction. This is one of the reasons why the vehicle deformation amount of the small family car was decreased (See Figures 16 and 17). Further, despite increased energy absorption share of the large saloon, toeboard and A-pillar intrusion amounts did not increase. We consider that the sub-frame and side member of the extension type of the large saloon car absorbed energy effectively without passing the energy on to its compartment, which enhances self-protection.

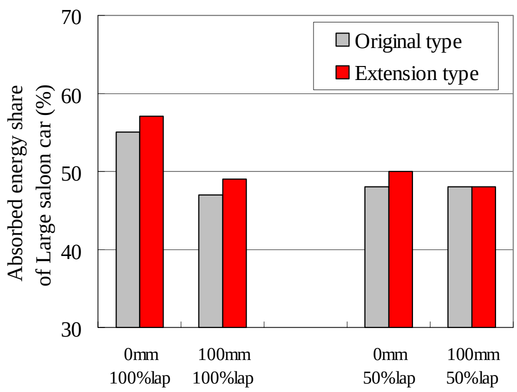

Figure 18. Energy absorption share of large saloon car.

Evaluation of Average Height of Force (AHOF)

This section explains the relation between AHOF and compatibility improvement effect displayed by the extension type in a vehicle-to-vehicle collision.
Vehicle-to-rigid barrier full-lap frontal impact test procedure to calculate AHOF is now under discussion by IHRA. In the present study, original type and extension type of large saloon car were impacted against a rigid barrier with load cell wall, as illustrated in Figure 19, under the following test specification by FEM:

- Test speed: 56km/h
- Aluminum honeycomb: without
- Load cell size: 125 x 125mm
- Load cell wall matrix: 16 x 10
- Load cell wall location: 125mm above the ground line

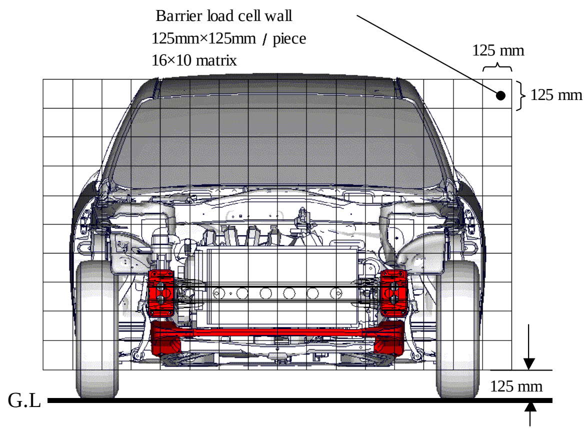

Figure 19. Relation of load cell wall and vehicle.

Figure 20 illustrates AHOF of original type and extension type. AHOF of the extension type within the first 25ms is lower than that of the original type. Specifically, at the initial stage of crash, AHOF of the extension type is lower approximately by 70mm compared to the original type.
As for the total load applied to the barrier load cell in Figure 21, total load of the extension type is higher than that of the original type until 15ms. Load distribution at 10ms is shown in Figure 22 for the original type and in Figure 23 for the extension type. Regarding load distribution of the extension type, load was applied in a lower and wider range of load cell walls compared to the original type. This is because extended sub-frame collided against the bottom row of load cell wall,

which made AHOF of the extension type lower than that of the original type.

The extension type improves vehicle front structural interaction and controls override/underrun effects even when there is height incompatibility. As for the relation between AHOF and improved interaction, it showed close relation during the initial crash, namely, within the first 25ms. Accordingly, in order to evaluate structural interaction in a vehicle-to-vehicle crash by means of a vehicle-to-rigid barrier test, the use of AHOF during the initial stage of the collision is practical. It is important to reduce the AHOF difference during the first stage of crash for compatibility improvement.

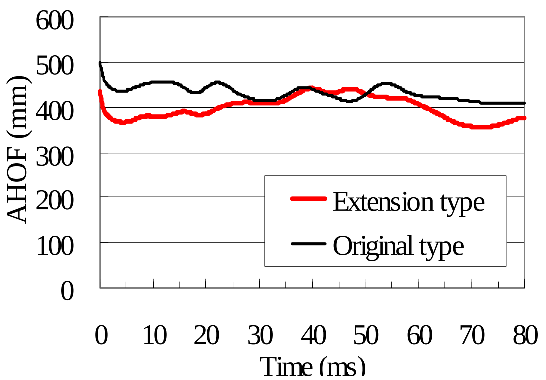

Figure 20. AHOF comparison.

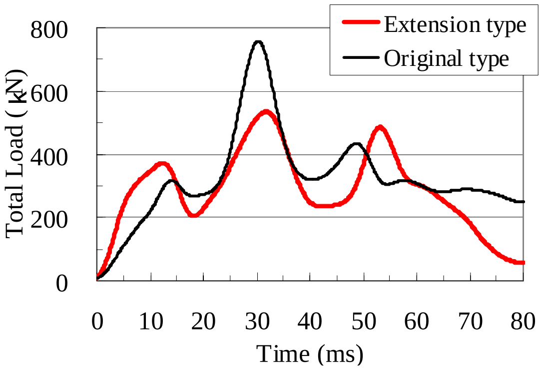

Figure 21. Load cell wall total load.

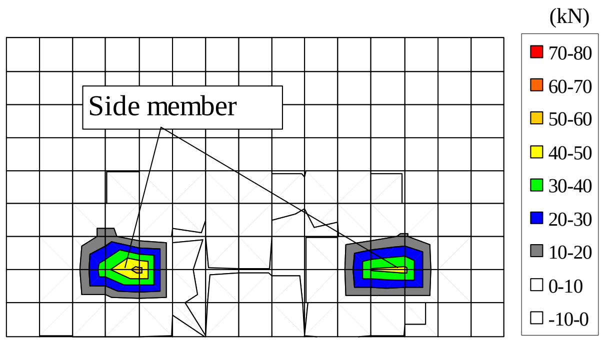

Figure 22. Load distribution of original type at 10ms.

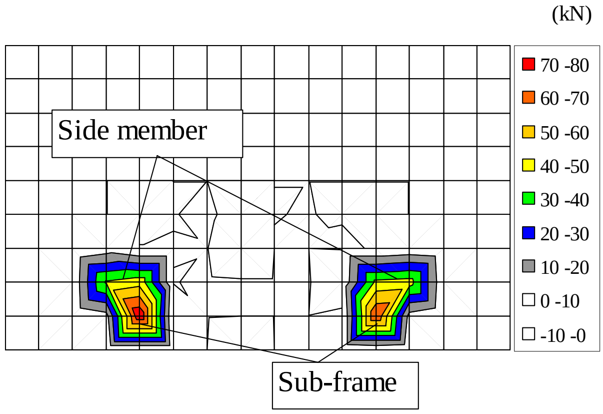

Figure 23. Load distribution of extension type at 10ms.

CONCLUSIONS

1. Forward-extended sub-frame structure has a possibility to improve compatibility for aggressivity and self-protection because of structural interaction enhancement and prevention of override.
2. Forward-extended sub-frame lowers the AHOF in a vehicle-to-rigid barrier full-frontal impact.

This study was conducted only on limited vehicles with and without sub-frame by CAE. The results are not applied to all cases and to every vehicle. Further study needs to be done on various vehicles because structure tends to depend on vehicle packaging that varies by vehicle.

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