

# A SIMULATION STUDY ON THE MAJOR FACTORS IN COMPATIBILITY

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## ABSTRACT

The evaluation method which simulates collisions between the subject vehicle and some other vehicle of a similar size has been developed up to now, by means of frontal impact to flat barrier or offset deformable barrier, etc. There are some reports describing that the injury level tends to become more severe for occupants of light vehicles than those of heavy vehicles, according to the accident data on vehicle-to-vehicle collisions. In this regard, the compatibility of heavy vehicles for the reduction of occupant injury level of lighter vehicles in such collisions is noted.

In this paper, the effect of factors has been studied by simulating the deformation of the struck vehicle. The influence on the impact performance of heavy vehicle into frontal impact barrier was also simulated.

## INTRODUCTION

The compatibility issue has been noted in recent years and related studies are being conducted at various research institutes. Although various proposals have been made so far, some of the proposals seem to contradict one another. Quantitative determinations of effects of individual factors have not become clear so far. Studies to estimate the effectiveness of each measure for the reduction of fatalities are also few.

It is likely that generally regarded major factors of compatibility are the vehicle weight, frontal stiffness and geometry. The effect of weight involves the following phenomena due to the laws of physics.

- A heavy vehicle requires a large amount of energy to be absorbed upon impact due to the large kinetic energy.
- In a collision between vehicles having different weights, the delta velocity ( $\Delta V$ ) of the lighter vehicle is higher than that of the heavier vehicle.

The injury level tends to become more severe for occupants of light vehicles than those of heavy vehicles, according to the accident data on vehicle-to-vehicle collisions. As the weight is closely related with other factors (vehicle size, stiffness, etc.), the quantitative determination of the effect of weight alone is not adequate.

The quantitative effect of stiffness or geometry has not become clear in accident analysis, since they have not been distinctively coded items in accident reports so far.

Some recent papers have noted that restraint systems in recent years (airbags, pretensioners, forcelimers, etc.) may have decreased some of the influences of the laws of physics by improving occupant protection. According to that, the data used for the accident analysis in this study are restricted to belted drivers, and classified by vehicle weight.

Considering the above, the effect of frontal stiffness or vehicle weight has been studied by simulation. The effect on the subject vehicle performance in frontal impact into barrier has been also simulated. The FEM simulation models were prepared in hybrid form of beam/shell elements for the reduction of calculation time.

## INVESTIGATION ON ACCIDENT DATA

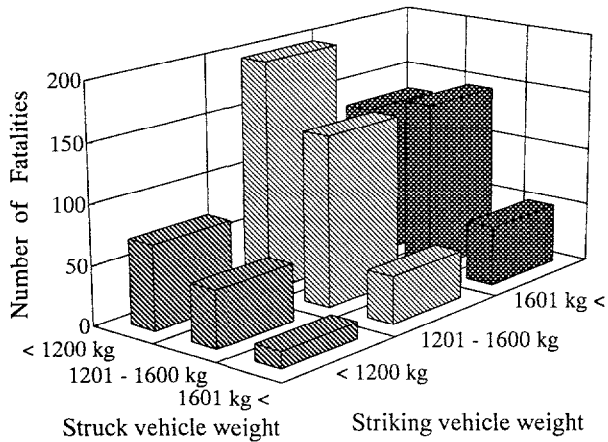
### Distribution of Fatalities in Vehicle-to-Vehicle Frontal Collisions Classified by Vehicle Weight

The investigation was conducted based on '91-'95 FARS accident data. The accident configurations subjected to this investigation were as follows - vehicles of '91 to '95 model year with fatalities of belted drivers, vehicle to vehicle frontal collisions, excluding those of heavy duty trucks and motorcycles. The vehicles were classified into three classes in this study: light vehicles with a weight up to 1200 kg; mid-size vehicles with a weight in the range of 1201 to 1600 kg; and heavy vehicles with a weight of 1601 kg or more. The numbers of fatalities of struck vehicles are plotted according to this classification (Figure 1).

The number of fatalities is the greatest for the mid-size striking vehicles, followed by heavy vehicles. The view that the injury risk increases as the weight of the striking vehicle increases is not clear. Factors that affect the absolute numbers of fatalities include the differences in the number of vehicles registered for each weight class, miles driven per year of each vehicle category, the frontal stiffness of the striking vehicle, etc. in addition to the vehicle

weight.

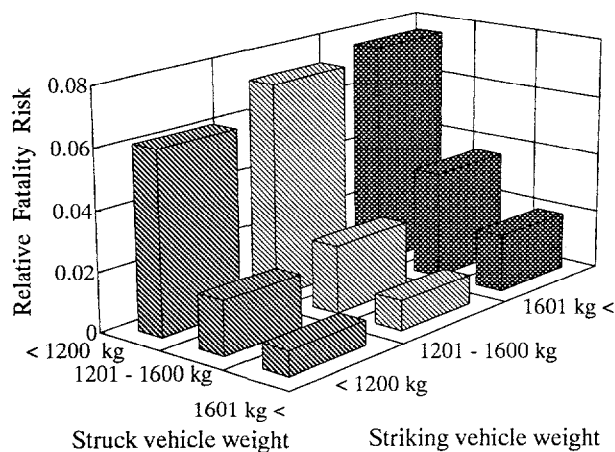
Accident data for cases with airbag deployments and driver fatalities were reviewed, but the sample size was so small that no conclusion could be made at this time.



**Figure 1. Fatalities distribution classified by vehicle weight, restricted to belted drivers in two vehicles frontal collisions.**

**Estimation of Fatality Risk Distribution Classified by Vehicle Weight**

To reduce the influence of the registration numbers of each weight class on the absolute number of fatalities, the relative fatality risk per one million registered vehicles was calculated for both striking vehicles and struck vehicles using the estimated cumulative data of the number of vehicles registered in '91 to '95. The distribution classified by vehicle weight is shown in Figure 2.

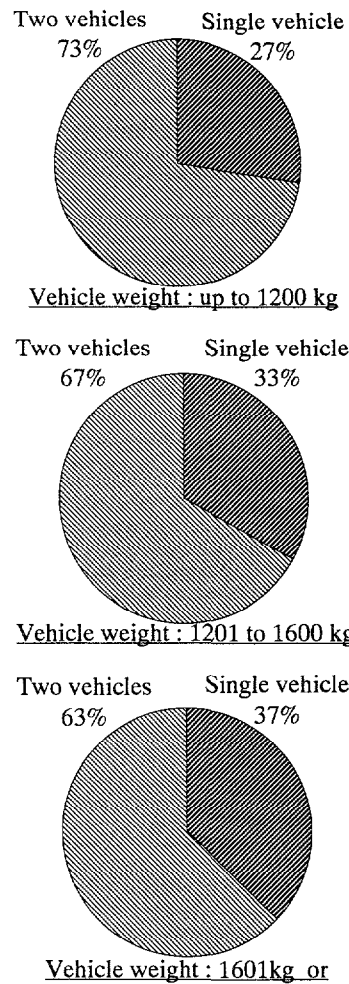


**Figure 2. Relative fatality risk distribution classified by vehicle weight, restricted to belted drivers in two vehicles frontal collisions.**

The effect of the striking vehicle's weight on the relative fatality risk indicates that the risk increases as the weight of the striking vehicle increases. According to the relative fatality risk distribution diagram, the risk is affected more significantly by the weight of the struck vehicle than the weight of the striking vehicle - possibly due to the restricted conditions (i.e. belted drivers, frontal collisions, etc.) of data investigated. As there are many other factors that affect the relative fatality risk including the frontal stiffness of the striking vehicle, miles driven per year, etc. in addition to the vehicle weight, efforts should also be made to determine their effects on the relative fatality risk.

**Opposite Object for Each Weight Class in Frontal Collisions**

The numbers of fatalities in single vehicle frontal collisions versus vehicle-to-vehicle frontal collisions have been investigated (Figure 3).



**Figure 3. Opposite object, restricted to belted fatal drivers in frontal collisions.**

Even in heavy vehicles, there are more fatalities in vehicle-to-vehicle frontal collisions than in single vehicle collisions. Further, the trend that the fatalities in single vehicle collisions increases as the weight increases is also observed. It is important to consider these facts.

## SIMULATIONS

### Preparation & Verification of Beam Element Models

To study the potential influence of factors other than vehicle weight, generalized simulation of impact were made using various finite element vehicle structures.

For the reduction of calculation time, beam element models excluding shell elements of front bumper and dash panel were prepared. The occupants were considered as nodal mass in the models. The number of beam elements for main body structures in each model was approximately 900 (Figure 4).

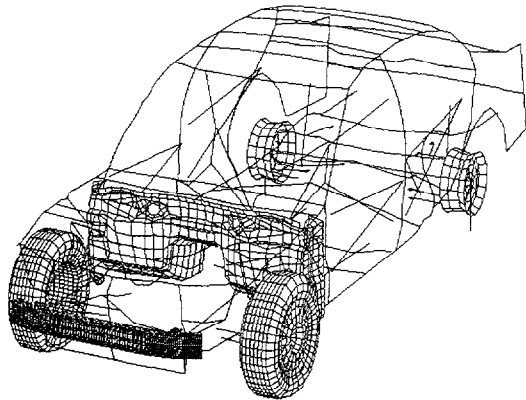


Figure 4. Beam elements model of body structures.

The models were verified by comparing the deformation - time characteristics with those of experimental data (Figure 5). The characteristics of each simulation model and the experimental data agreed fairly well.

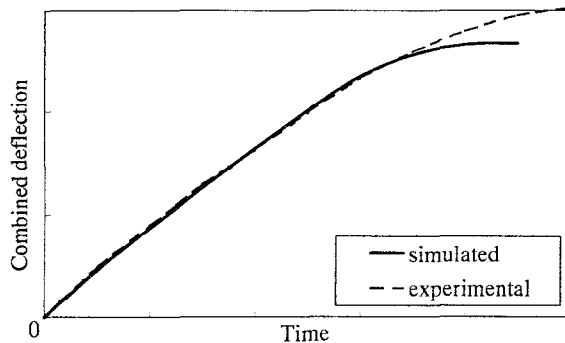


Figure 5. Comparison of simulated and experimental deflections in heavy car frontal impact to offset deformable barrier.

Two passenger car models - a light car (gross vehicle weight including the occupant mass: 1100 kg) and a heavy car (GVW including the occupant mass: 1700 kg) - were prepared. All simulations of car-to-car frontal impact were conducted at a closing speed of 100 km/h.

### Striking Car Models & Struck Car Deformation

The effect of differences of striking car characteristics on the deformation of the struck car in offset frontal impact was investigated using simulations. The effect of frontal overlap percentage was also studied. The overlap here refers to the percentage of overlap against the overall width of the struck car. The struck car was a light car and the simulation was conducted for both light and heavy striking cars. The  $\Delta V$  was 50 km/h for both striking and struck cars in the case where both cars were light, while it was 61 km/h for the struck light car and 39 km/h for the striking heavy car in the case of light car-to-heavy car impact due to the laws of physics.

The comparison of both cases where the overlap percentage are the same shows that the passenger compartment intrusion of the struck car struck by the heavy car is larger than struck by the light car (Figure 6). In cases where the overlap drops to 40 %, however, the light car deformation struck by a heavy car also drops to the same level as that of the case with the overlap exceeding 60 % struck by a light car. Hence as expected, the deformation of a struck vehicle is affected by the characteristics of the striking car models and also the impact overlap percentage.

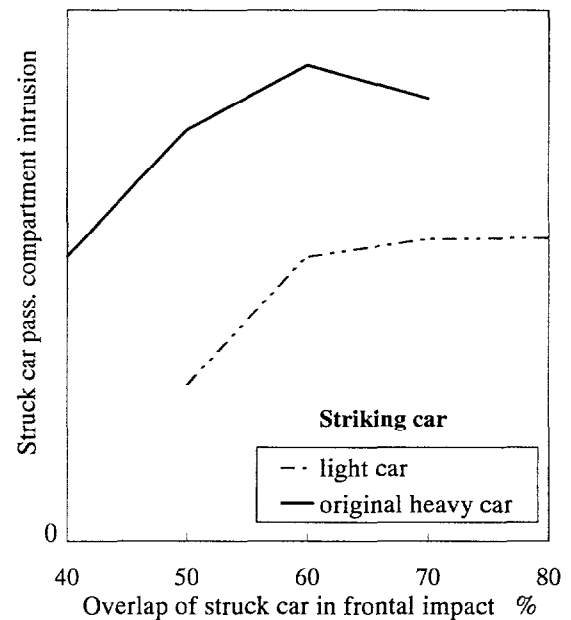


Figure 6. Effect of striking car model.

## Frontal Stiffness & Struck Car Deformation

The comparison of deformations between the cars shown in Figure 6 indicates that the struck car deformation is 1.7 times greater with the impact from the heavy car compared to the impact from the light car. For the investigation of the major factor of this phenomenon, the frontal stiffness or the mass of the striking heavy car was varied in simulations of impact configurations. Namely, the frontal stiffness of the heavy car was set at two levels - with 50 % increase and 50 % decrease, respectively, compared with the original level - while the weight was kept constant (Figure 7). The struck car deformation tends to be smaller as the striking car frontal stiffness is reduced (Figure 8), but the difference is smaller compared with the difference in frontal stiffness - i.e., 50 % difference in frontal stiffness versus 3 % or less difference in passenger compartment intrusion.

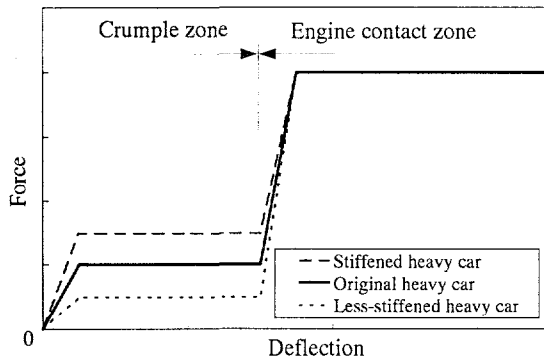


Figure 7. Comparison of heavy cars front stiffness, simplified diagram.

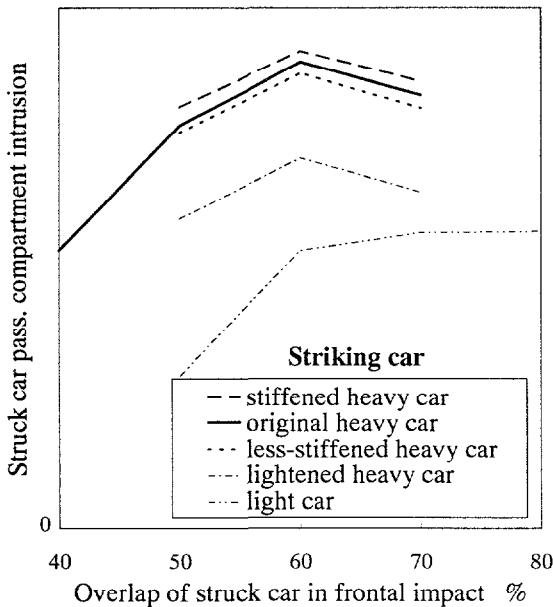


Figure 8. Effect of striking car's factors.

Figure 9 shows the car deceleration characteristics of the striking and struck cars. One of the factors of the above is due to this characteristics. The difference in frontal stiffness affects not only the struck car deformation but also the both cars deceleration dynamic characteristics. The deceleration in the initial stage of impact decreases with the drop of frontal stiffness due to the laws of physics, which, however, ultimately results in a greater overall deformation than those of the light car struck by an original stiffness heavy car. The combined deformation of both cars is represented by an area enveloped by the lines of deceleration characteristics of the striking and the struck cars. The reduction of the striking car's frontal stiffness shifts some of the combined deformation from the struck car to the striking car, but there is an overall increase in combined deformation due to the effect on the car deceleration dynamic characteristics. Consequently, it results in a smaller reduction of deformation of the struck car.

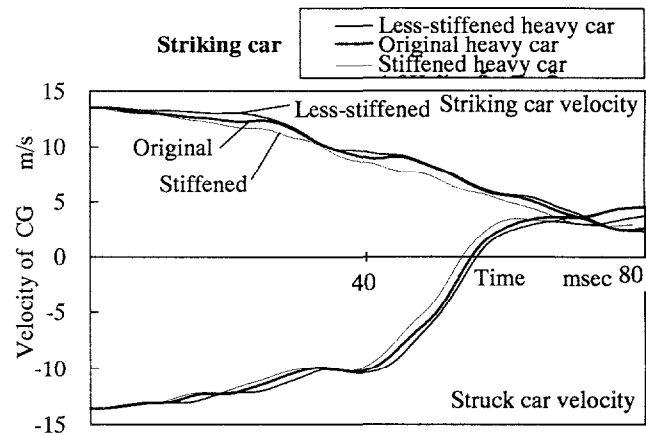


Figure 9. Vehicles deceleration characteristic.

## Car Weight & Struck Car Deformation

In other simulation, the stiffness was kept constant while the weight was reduced by 300 kg. The deformation of the struck car was reduced in accordance with the laws of physics (Figure 8).

## Effect of Stiffness on Subject Car Frontal Impact to Barrier

Simulations were conducted to observe the effect of frontal stiffness on the performance of the heavy striking car in the offset frontal deformable barrier impact. The intrusion tends to increase as the frontal stiffness drops (Figure 10). (19 % intrusion change caused by 50 % stiffness change)

Therefore, the reductions of frontal stiffness will have to be compensated for by increasing the vehicle's frontal crumple zone length. However, extending the car length will in-

crease the weight of the car which will affect the struck car's performance in car-to-car frontal collision.

By comparing the effect on the struck car's deformation in car-to-car frontal impact and the effect on the striking car's performance in offset frontal barrier impacts, the striking car's stiffness has little effect on the struck car deformation (19% the striking car's intrusion change in barrier impact versus 3% the struck car's intrusion change in car-to-car impact).

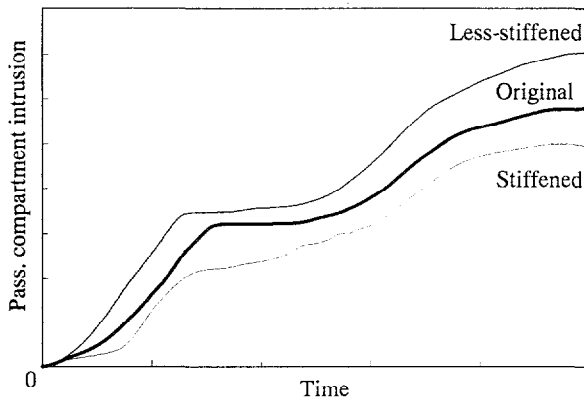


Figure 10. Effect of stiffness on deformation in offset frontal impact to deformable barrier.

## SUMMARY

In accident data investigation, the effect of vehicle weight on the occupant fatality risk is observed. The quantitative effect of vehicle weight on occupant fatality risk cannot be determined, since there are some other factors which are not coded in existing accident data.

Computer simulations, however, can provide insights about the effect of weight and frontal stiffness characteristics of the striking car on the struck car's deformation.

- The simulations suggest that a 17% weight reduction of the striking car has a larger effect on compatibility than a 50% reduction of frontal stiffness in the striking car.
- Decreasing the stiffness of the striking car will reduce some deformation of the struck car. However, reducing the stiffness of the car will increase deformation of the car in frontal barrier impact testing.

The relationship between intrusion and occupant fatality risk is not yet clear. Efforts should be made in the future for the analysis of accident data with respect to air-bag systems and for the determination of the relationship between the vehicle intrusion and occupant fatality risk according to the results of accident data analysis.

## REFERENCES

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