HEAVY DUTY VEHICLE CRASH TEST METHOD IN JAPAN

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Paper Number 98-S4-O-13

ABSTRACT

In recent, safety measures for occupants in heavy duty vehicle collisions such as for buses and trucks have been studied intensively in Japan. However, domestic guidelines for crash tests for heavy duty vehicles were not available in Japan prior to this study. Japan Automobile Research Institute (JARI) has started to study standard guidelines for heavy duty vehicle crash tests with the contract by Japan Automobile Manufacturers Association (JAMA).

This paper investigated configurations of heavy duty vehicle accidents. Then guidelines for crash tests of buses and trucks have been formulated accordingly. The guidelines can evaluate occupant injuries similar to frontal impact regulation for passenger cars in Japan (Article 18, Safety Regulation for Road Vehicles). Vehicle crash tests have also been conducted to verify the guidelines. It is found that the guidelines are satisfactory for heavy duty vehicles.

INTRODUCTION

The number of fatalities caused by automobile traffic accidents amount to about 10,000 per year, still showing a quite serious situation. In order to improve this situation, governments and automobile manufacturers have been studying safety measures against accidents. In the studies related with heavy duty vehicles such as buses and trucks, their aggressiveness to the passenger car occupants and safety measures for the heavy duty vehicle occupants have been studied . For the aggressiveness, measures to prevent passenger car underrun in rear-end collision with heavy duty vehicles have already been made mandatory. Studies to prevent the underrun of passenger cars in head-on collisions have been made since then.

As regards to the safety measures for the heavy duty vehicle occupants, the active and passive safety measures have been studied by vehicle manufacturers. In recent years, attempts to improve crash safety measures for the heavy duty vehicle occupants have been made. The Bus subcommittee and the Cab subcommittee under the Heavy Duty Vehicle Committee of JAMA have been studying on crash safety of heavy duty vehicles since April 1996. At the end of 1995, "The Technical Committee for Safety Crashworthiness and Occupant Protection of the Bus" was established by the Japan Bus Association, and "Second Stage of Advanced Safety Vehicle (ASV)" was formed by the Ministry of Transport in early 1996. Moreover, "The Technical Committee for Safety Crashworthiness and Occupant Protection of the Truck" was established by the Japan Truck Association in late 1996, and studies on practical measures to improve the safety of heavy duty vehicle occupants have been conducted actively by these committees since then.

Under such circumstances, crash test methods to evaluate occupants safety performance for the heavy duty vehicle must be set first. However, guidelines for heavy duty vehicle crash tests were not available in Japan, even if each manufacturer in house has set crash test methods. Therefore, it was requested by JAMA that JARI has started to study domestic guidelines for heavy duty vehicle crash tests.

This paper studied real world accidents involving heavy duty vehicles, and proposed two guidelines for crash tests of bus and truck, based on the passenger car frontal impact regulation in Japan. Finally, crash tests for heavy duty vehicles were carried out according to the proposed guidelines in order to verify their feasibility, which will be also discussed in this paper.

ACCIDENTS

In order to obtain more realistic test conditions based on actual accidents involving heavy duty vehicles in Japan, national traffic accident statistics for three years (1992 to 1994) for buses and one year (1995) for trucks were analyzed. The accident statistics data on buses and trucks will be described in the following.

Buses

Occupant injuries on large buses with gross vehicle weight of 12 tons, or of heavier category, were analyzed.

Figure 1 shows the severity of occupant injuries classified by its seating positions - i.e., driver seat and passenger seats on the buses (including tour guide seat). The number of passengers who sustained serious or minor injuries is greater than the number of drivers. One of the reasons for the above should be attributed to the greater number of passengers than one driver in each bus. The number of fatal injuries, on the other hand, is greater for drivers.

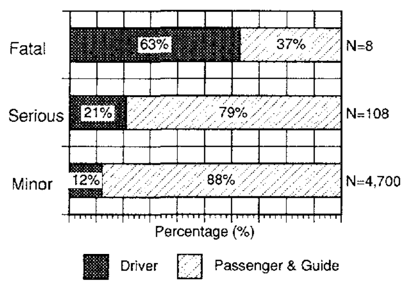


Figure 1 . Severity of occupant injuries classified by its seating position on the buses .

Figure 2 shows the severity of injuries on bus occupants divided into two categories: types of accidents - i.e., vehicle-to-vehicle accidents and single vehicle accidents, such as vehicle-to-object or rollover accidents, and seating position. It is found that vehicle-to-vehicle accidents account for more than 70 % of all severity of injuries, regardless of the seating positions. The rate of such accidents is particularly high (90 % or more) for fatal and minor injuries of passengers and minor injuries of drivers.

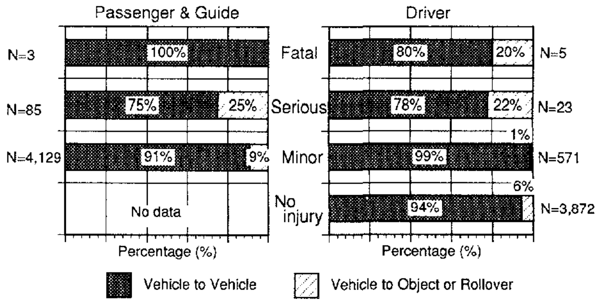


Figure 2. Severity of injuries on bus occupants divided into seating position and two types of accidents.

Taking into account such high percentages of vehicle-to-vehicle accidents, the damaged area of buses are classified into four types : frontal, side, rear and unknown, in Figure 3. Figure 3 also shows the incident rate according to the seating position and the severity of injuries. In case of fatal or serious injuries of bus occupants, frontal impacts account for approx. 70 % of the total, and the percentage is especially high for drivers (90 % or higher).

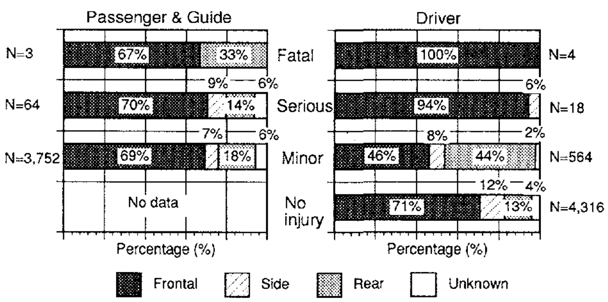


Figure 3. Severity of injuries on bus occupants classified by seating position and damaged areas of buses

Frontal impacts, with the highest incidence rate among the vehicle-to-vehicle accidents, are classified further into four types for buses. These are head-on, intersection, rear-end and others. The severity of injuries on bus drivers classified by accident type are shown in Figure 4. In case of driver fatalities, rear-end collisions show the highest percentage, while head-on collisions show the highest percentage of severe and minor injuries (excluding others). However, head-on collisions account for the highest rate of total number of fatal and serious injuries even if the number of the driver fatalities is very small (4 drivers only).

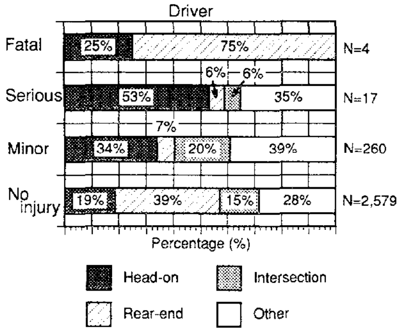


Figure 4 . Severity of injuries on bus drivers classified by the type of accidents.

Figure 5 shows the severity of injuries on bus driver in head-on collisions and rear-end collisions, classified by the type of opponent vehicles involved in such accidents. In the figure, the fatalities of drivers are so few that the fatal and serious injuries are combined into a single percentage. Large trucks (GVW> 12t) account for the highest rate of both fatal and serious injuries of bus drivers, while passenger car collisions account for the highest rate of minor or no-injury cases for the bus drivers.

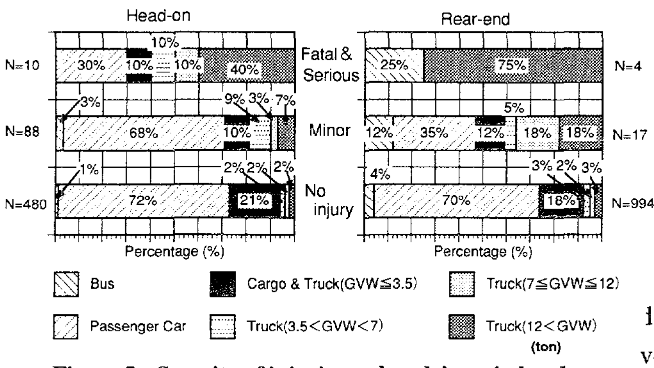


Figure 5. Severity of injuries on bus drivers in head-on collisions and rear-end collisions classified by the types of opponent vehicles

According to the above results, it is necessary to consider the injury reduction on bus drivers and passengers respectively for the establishment of large bus test conditions. As for the type of accidents involving bus, frontal impacts in vehicle-to-vehicle accidents should be in high priority, and that the head-on collision is a particularly important type of accident to be evaluated. As regards to the type of opponent vehicles involved in each accident, it is necessary to keep in mind that a passenger car is the most significant counterpart in terms of all types of accidents, though large trucks account for the majority of serious or fatal injuries.

2.2 Trucks

Occupant injuries on large trucks with the gross vehicle weight of 12 tons or more were analyzed, as in the case of truck occupants.

Figure 6 shows the severity of occupant injuries classified by its seating position on the trucks. It is found from the figure that the drivers account for more than 90 % of all injuries regardless of the severity of injury. Therefore, it was decided to consider only the drivers in the analysis as far as truck accidents were concerned.

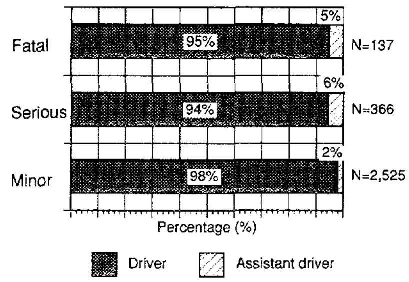


Figure 6. Severity of occupant injuries classified by its seating position on the trucks

Figure 7 shows the severity of injuries on truck drivers livided into two types of accidents. Injuries caused by vehicle-to-vehicle accidents account for more than 70 % of the total number of accidents, with the rate becoming even higher for serious and minor injuries.

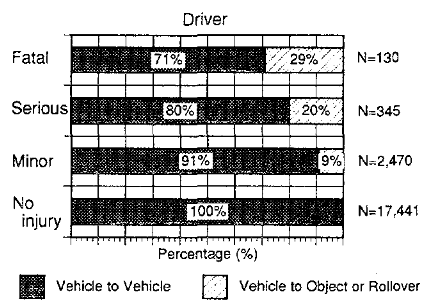


Figure 7. Severity of injuries on truck drivers divided into two types of accidents.

Figure 8 shows the severity of injuries on truck drivers classified by damaged areas of trucks, focusing on the vehicle-to-vehicle accidents that occur most frequently as described above. The more severe the injury becomes, the greater the number of occupants injured by frontal impacts becomes. This accounts for more than 80 % of the fatal and serious injuries.

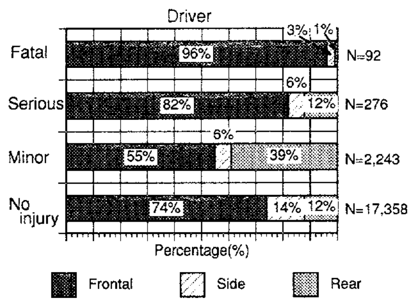


Figure 8 Severity of injuries on truck drivers classified by damaged areas of trucks

Figure 9 shows the severity of injuries on truck drivers classified by the type of accidents, focusing on frontal impacts that occur frequently as in the case of buses. It is found from the figure that rear-end collisions and head-on collisions show high percentages which amount to more than 70 % of the serious injuries and more than 80 % of the fatal injuries.

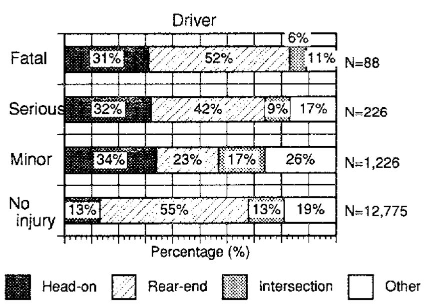


Figure 9. Severity of injuries on truck drivers classified by the type of accidents.

Figure 10 shows the severity of driver injuries in head-on collisions and rear-end collisions, classified by the type of opponent vehicles involved in such accidents. The more severe the injury becomes, the greater the percentage of large trucks becomes. This accounts for more than 80 % of fatal injuries for both head-on collisions and rear-end collisions. On the other hand, the percentage of passenger cars is greater than that of large trucks in case of minor injuries sustained by truck drivers in head-on collisions.

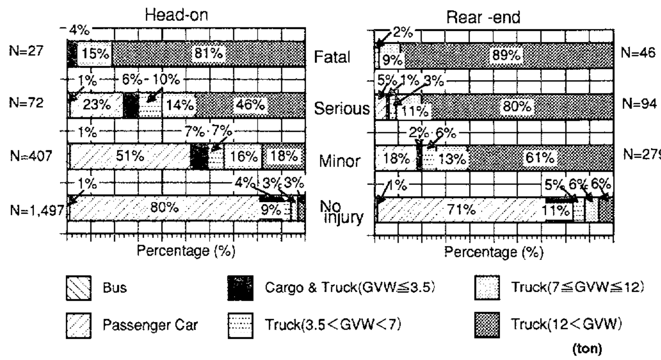


Figure 10. Severity of injuries on truck drivers in head-on collisions and rear-end collisions classified by the types of opponent vehicles

According to the results described so far, it is vital to evaluate accidents involving truck drivers for the establishment of large truck test conditions. It is particularly necessary to consider both head-on collisions and rear-end collisions. As regards to the type of opponent vehicle involved, large trucks are the most important type to consider. However, it is necessary to keep in mind that passenger cars and other types of vehicles should be also studied as the counterparts in the accidents.

CRASH TEST METHOD

Based on accidents involving buses and trucks, we have established crash test guidelines respectively for large buses and trucks. We have followed the procedure in Figure 11 showing the test method to be incorporated in the guidelines. Namely, the crash patterns for test was selected first, then the test speed was set for the selected crash patterns. These test conditions were compared with the existing frontal impact regulation for passenger cars in Japan, then Hy-III and Hy-II dummies were selected as evaluation tool and the number of dummies was determined.

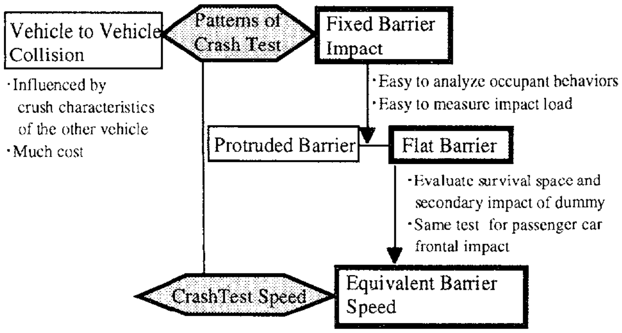
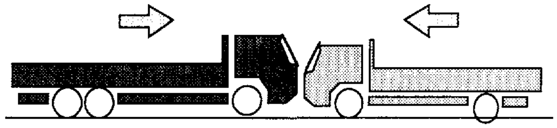
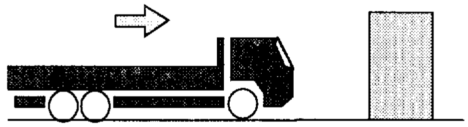


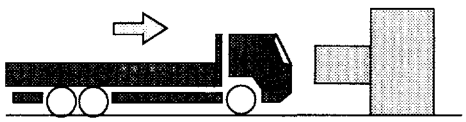
Figure 11. Crash test procedur



(a) Vehicle-to-vehicle collision



(b) Fixed barrier impact (Flat barrier)



(c) Fixed barrier impact (Protruded barrier)

Figure 12 Patterns of crash tests

Patterns of Crash Tests

According to truck and bus accident data, frontal impacts in vehicle-to-vehicle accidents account for the majority. In this regard, the patterns of crash tests to simulate such frontal impacts were studied.

For heavy duty vehicles, two kinds of test methods - "vehicle-to-vehicle collision" and "fixed barrier impact" - can be considered as candidates. The vehicle-to-vehicle collision here refers to the crash tests shown in Figure 12 (a), in which a test vehicle collides against an equivalent vehicle. The fixed barrier test is to collide a test vehicle against a fixed barrier as shown in Figure 12 (b) and 12(c). We decided to use the fixed barrier test method due to the following reasons. The first reason is that the method is not influenced by crush characteristics of the front cab (structure) of opponent vehicle, and reproducibility is preferred. The second reason is that it is easy to analyze occupant behaviors and to measure impact loads. The third reason is the fact that it is the common method employed for the passenger car frontal impact tests, which makes standardization easy.

Two kinds of configurations were considered next for the plane of fixed barrier. These are "flat barrier" and "protruded barrier" which were considered as candidates for the configurations of fixed barrier. The flat barrier here means a flat plane against which the front of a large truck collides as shown in Figure 12 (b) as with the case of the passenger car frontal impact tests. The protruded barrier, on the other hand, represents the simulated configuration of the end of a truck cargo, assuming a rear-end collision as shown in Figure 12 (c). We decided to apply the flat barrier due to the following reasons. The primary reason is to evaluate the survival space which affects the severity of occupant injuries, and at same time, to measure the outcome caused by the secondary impact onto the steering wheel, instrument panel, etc. The second reason is that the flat barrier is the same as that used in the passenger car frontal impact tests, which makes standardization easy.

Crash Test Speed

The crash test speed was set as the equivalent barrier speed. The equivalent barrier speed, however, cannot be derived directly from the statistics analyzed in this study, as the crush characteristics of individual vehicles involved in accidents are not available in those data.

Therefore, it was decided to obtain the equivalent barrier speeds of large buses and trucks by means of the following. That is, each equivalent barrier speed was calculated by substituting the weight, impact speed and crush stiffness of the vehicle concerned into Equation (1). The equation is based on the energy conservation law and the momentum conservation law. In such calculations, the vehicle weight was set for each type of vehicle, taking into account the loading condition, which was obtained from the data. As for the impact speed, the value was obtained by multiplying by a given factor the travel speed obtained from the statistic data. The crush stiffness for each vehicle was set by using the value obtained by the heavy duty vehicle crash tests conducted thus far.

$$V_b=(V_{10}-V_{20})\sqrt{\frac{M_2k_2}{(M_1+M_2)(k_1+k_2)}} \quad \cdots (1)$$

V_b: equivalent barrier speed of bus (truck)
V_{10}: impact speed of bus (truck)
V_{20}: impact speed of the other vehicle
M_1: bus (truck) weight upon accident
M_2: weight of the other vehicle upon accident
K_1: crush stiffiness of bus (truck)
K_2: crush stiffiness of the other vehicle

Based on the assumptions described above, the equivalent barrier speed of each vehicle was calculated with Equation (1), according to the accident data of 280 large buses involved in head-on collisions and 9,270 large trucks involved in head-on and rear-end collisions. The crash test speeds of large buses and trucks were calculated respectively, and the speeds covering more than 90% of all accidents are as follows.

(1) Large bus : test speed, 35 km/h
(2) Large truck : test speed, 40 km/h

Dummies, etc.

Dummies of the same type (Hy-II and Hy-III) as those used in the frontal impact regulation for passenger cars in Japan were used in the test vehicles. Six dummies in total were set in each bus for the driver, tour guide and passengers , while two dummies (driver and assistant driver) were set in each truck. Test vehicle weight and other test conditions were set similar to those for the regulation for passenger cars. Table 1 shows the results of comparison between the bus and truck test conditions set according to the above.

Table 1
Test conditions for Bus and Truck

Vehicle		Large Bus (GVW > 12t)	Large Truck (GVW > 12t)
T	Pattern	Flat barrier impact	Flat barrier impact
E	Speed	35km/h	40km/h
S	Mass	Vehicle + Dummies	Vehicle + Dummies
T	Dummy	6 dummies (Hy-II or Hy-III)	2 dummies (Hy-II or Hy-III)

EXPERIMENTS

Large bus and large truck crash tests were conducted according to the guidelines set for frontal impact tests. Figures 13 and 14 show examples of the test results of bus and truck driver dummies after the crash tests.

The test results such as interior damage, steering wheel contact of the bus driver dummy, etc. after the experiment are shown in Figure 13. The legs of the driver are caught between the instrument panel and the seat, and the abdomen is pressed by the steering wheel and the seat due to narrowing survival space for drivers. Such conditions are similar to those found in real world accidents which result in serious and/or fatal injuries of drivers [2), 3)].

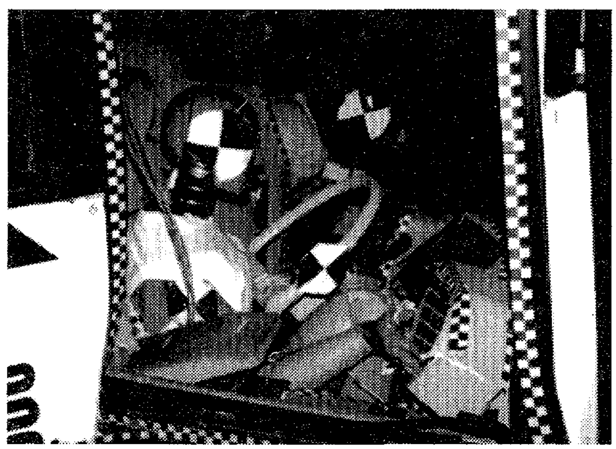


Figure 13. Interior damages and conditions of driver dummy on large bus after the experiment.

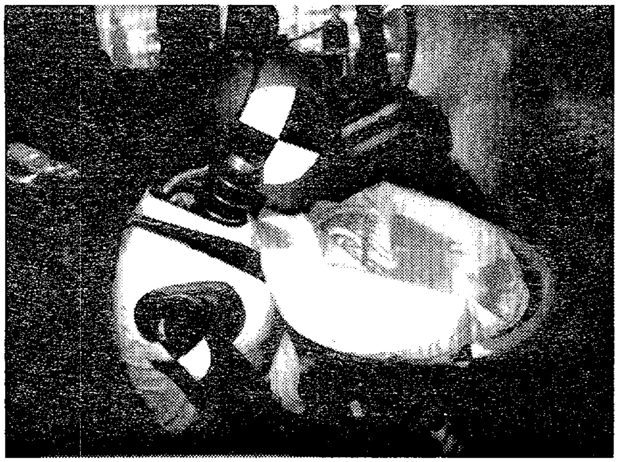


Figure 14. Conditions of driver dummy with deployed airbag on large truck after the experiment.

As described so far, the frontal impact test of large buses have reproduced the situations found in real world accidents, showing the appropriateness of the test conditions for the evaluation of crashworthiness of heavy duty vehicles. Although it is necessary to make further studies on dummies as the abdomen injuries cannot be evaluated quantitatively using existing dummies, evaluations of indices of other injuries have become possible as in the case of passenger cars.

Figure 14 shows the situation around a large truck driver. This truck was equipped with the most advanced crash safety devices such as an airbag, pretensioning seat belt, etc. It is possible to evaluate the dummy injuries in relation to such advanced crash safety devices under the test conditions we have set, same as in the case of frontal impact test for passenger cars.

It will be necessary to collect more basic data on bus and truck crush characteristics and occupant injuries and to evaluate abdominal injuries which typically occur in heavy duty vehicle accidents for the enhancement of safety measures.

CONCLUSIONS

Configurations of heavy duty vehicle accidents were investigated, and guidelines for crash tests of bus and truck have been formulated. Vehicle crash tests have been also conducted according to the guidelines. The main results are as follows.

1) It is found from the analysis of accident data that frontal impact against the other vehicle shows the highest rate. In particular, head-on collisions are the highest for buses, while both rear-end and head-on collisions account for the majority for trucks.
2) Guidelines for crash test of heavy duty vehicles has been formulated based on the analysis. Flat barrier impact is used for the frontal crash test, and the test speed is set at 35 km/h for large buses and at 40 km/h for large trucks.
3) Crash tests have been conducted according to the proposed guidelines. As a result, it is found that the guidelines are satisfactory for heavy duty vehicles.
4) It will be necessary to carry out further studies on the evaluation of typical injuries in heavy duty vehicle collisions, abdominal injuries in particular.

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