Experimental Research on Truck Driver's Safety in Frontal Collision

Yoshihiro SUKEGAWA, Fujio MATSUKAWA
Japan Automobile Research Insutitute
Naoki MASUDA
Japan Automobile Manufacturers Association Inc.
Japan
Paper Number 224

Abstract

The Japan Automobile Manufacturers Association Inc. (JAMA) has been working to promote crash safety measures and to evaluate the crash safety performance of heavy-duty trucks. The Japan Automobile Research Institute (JARI) has been studying these issues at the request of JAMA. "The Guidelines for Frontal Crash Test of Heavy-duty Trucks" were formulated as a first step[1]. Furthermore, crash tests of the latest heavy-duty trucks based on the guidelines were conducted. Equipped with the latest safety systems, each truck met all the judgments of the guidelines.

For further improvement of safety performance, it is necessary to study the specific causes of truck occupant injuries. Numerous truck driver fatalities have been caused in Japan by frontal collisions, in which the truck driver is often injured in the chest and the abdomen by the steering wheel. However, no evaluation techniques for such chest and abdominal injuries have yet been established. Moreover, truck drivers are often trapped in the truck cab in collisions.

Therefore, JARI has started evaluation of chest and abdominal injuries. Improvements in rescue performance were also studied beginning in 1999. Attempts were made in such injuries to measure the deflection of the sternum in more detail. Better rescue performance was examined by interviews with rescue teams.

1. Introduction

Around 9,000 people are killed yearly in traffic accidents in Japan, reflecting a still severe situation. The government of Japan aims to reduce by 1,200 the number of traffic fatalities by 2010, and is investigating ways and means to assure safer vehicle and safety equipment. Ongoing discussion of heavy-duty truck safety measures includes efforts to provide more protection for pedestrians and passenger cars along with truck occupants.

As for the aforementioned protection (i.e., aggressiveness), "Side Guards" and "Rear Underrun Protection Devices" are already made regulations. Also, examinations are now under way to put in place the "Front Underrun Protection Device" (FUPD) for frontal collisions into trucks by passenger cars.

As for occupant protection, "The Guidelines for Frontal Crash Test of Heavy-duty Trucks," which aim to evaluate the safety performance of the truck occupant, were formulated at the end of 1998[1]. The safety measures for truck occupants have been further improved by conducting crash tests in accordance with these guidelines.

However, it is necessary to examine further safety measures to achieve government targets. The truck driver is often injured in the chest and abdomen by the steering wheel in fatal or serious accidents. In such cases, truck drivers are often pinned in the truck cab.

In the light of this situation, the cab subcommittee working under the heavy-duty truck committee of JAMA began the study of injuries peculiar to truck drivers. JARI started this line of research under contract to JAMA.

The present report describes the accident situation and the safety measures used for heavy-duty trucks in Japan, and the studies of injuries peculiar to truck drivers.

2. Accident situation and safety measures in Japan

2.1 Accident situation

About 550 people in all suffered serious injuries or fatal injuries in Japan in 1999. The trend was shown in Figure 1. The number reached its peak around 1996, and then

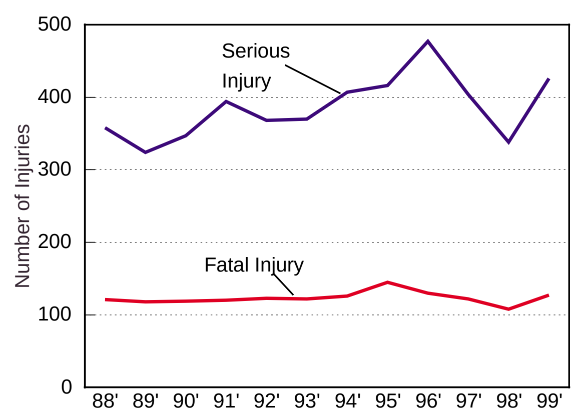


Fig. 1 Annual transition of fatalities in heavy-duty truck occupants

tended to decrease afterwards. However, the number increased again in 1999.

Figure 2 shows the breakdown of truck accidents. Frontal and rear-end collisions were the most common.

In these accidents, the relationship between the injury region and the contact point for truck drivers is shown in Figure 3. The number of leg (and arm) injuries caused by the instrument panel etc. is the highest, followed by chest and abdominal injuries caused by the steering wheel. The number of chest and abdominal injuries caused by the steering wheel is the highest fatal injury factor.

Therefore, chest and abdominal injury by the steering wheel and leg injury by the instrument panel etc. are among the injury factors peculiar to truck drivers.

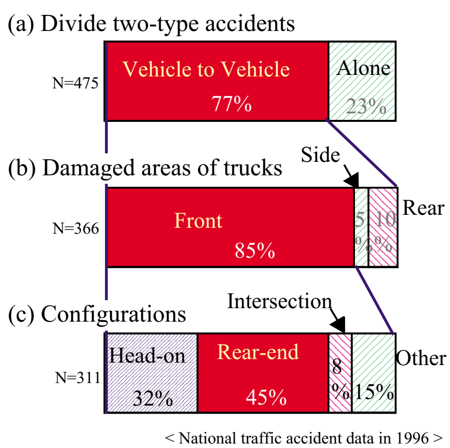


Fig. 2 Breakdown of accidents (fatal and serious injuries of heavy-duty truck driver)

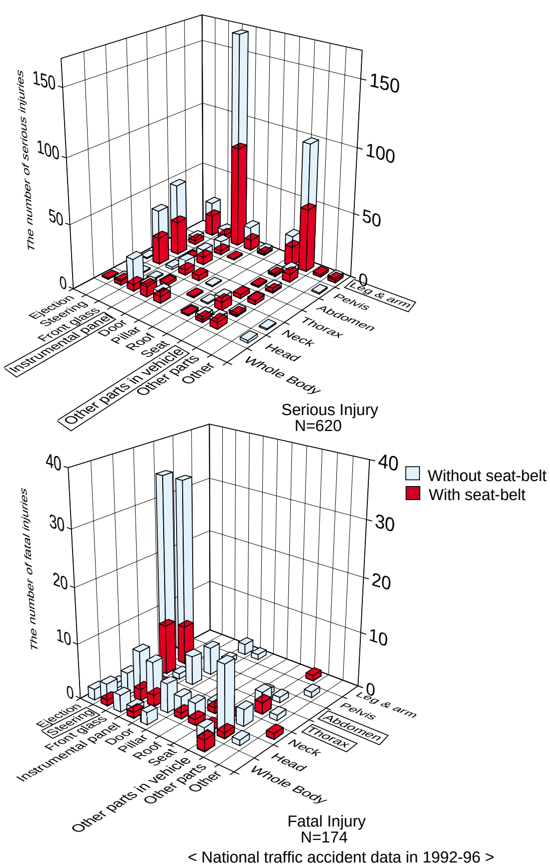


Fig. 3 Relationship between injury region and contact point (Head-on collision and rear-end collision accident)

2.2 Safety measures

Truck manufactures in Japan work hard to assure the safety of occupants. Figure 4 shows the improved safety measures taken for the latest heavy-duty trucks. Moreover, "The Guidelines for Frontal Crash Test of Heavy-duty Trucks" were formulated[1]. These guidelines call for heavy-duty trucks to be collided with a fixed flat-barrier, and they evaluate the safety performance according to the injury criteria for the dummy (Table 1). The impact energy caused by this test is larger than the one by the test based on ECE29.

Crash testing of the latest heavy-duty trucks based on these guidelines was conducted in three cases. As a result, each truck met all the judgments of the guidelines (Figure 5).

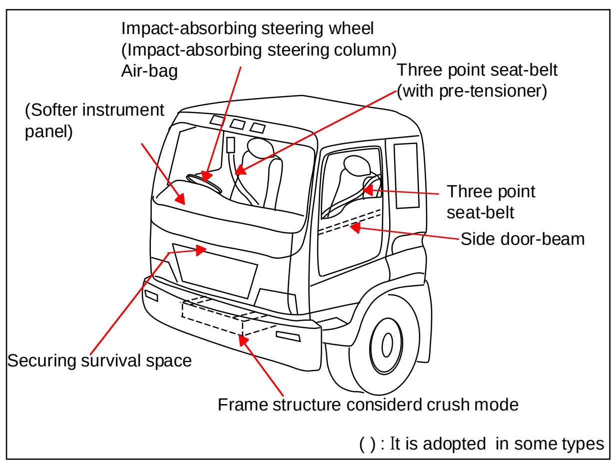


Fig. 4 Passive safety measures

Table 1 Guideline for crash test of heavy-duty trucks

Vehicle		Heavy-duty truck (GVW>12ton)
Configuration		Flat barrier impact
Impact velocity		40 km/h
Vehicle mass		Unloaded vehicle mass + Dummies
Dummy	Type	Hybrid-II & III
	Position	driver's seat, assistant seat
Target	Head	HIC≦1000
	Chest	Accel.(3ms)≦60 G
	Femur	Load≦10 kN

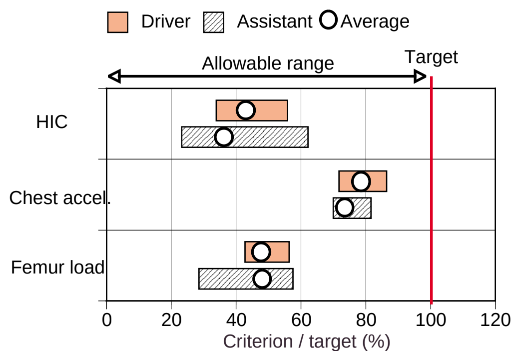
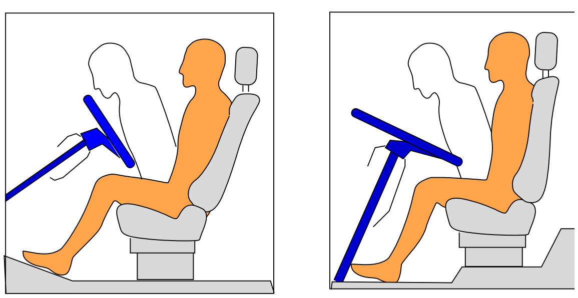


Fig. 5 Results of crash tests

3. Evaluation technique for chest and abdominal injuries

3.1 Measurement technique

Chest and abdominal injuries by the steering wheel are among those peculiar to heavy-duty truck drivers. The difference in the steering wheels between a heavy-duty truck and a passenger car is thought to be a big factor. The size and the installation angle of the steering wheel are very different (Figure 6). As a result, the chest and abdomen of a truck driver are often struck by the bottom part of the steering rim in a frontal accident. This was thought to be a form peculiar to truck driver injuries. Therefore, it is necessary to evaluate this form when investigating further safety measures.



(a) passenger car **(b) heavy duty truck**

Fig. 6 Driving position and steering position

A chest displacement meter is installed in the Hybrid-III dummy, which is used to evaluate chest injury from a frontal collision. Evaluation by chest deflection (displacement) is assumed to be effective in cases of sternum fracture[2) 3) 4)].

However, the deflection measured by the meter tends to be small as the point of contact is further away from the meter[5)]. This is because the chest displacement meter equipped in the Hybrid-III measures only one point on the sternum. This tendency is especially remarkable in connection with contact with a narrow object such as a steering rim[6)].

Therefore, attempts were made to measure the deflection of the sternum in more detail as a means to determine the chest injury and upper abdominal injury when evaluating a sternum fracture.

In this measurement technique, single axis strain gauges are pasted on six locations in all (right and left first rib, third rib, and sixth rib) (Figure 7). Each rib deflection of the time series is calculated from the output value of each strain gauge.

As shown in Figure 8, there seems to be a good correlation between the strain and the rib deflection in the calibration test results. Therefore, it is thought that the deflection of the sternum can be measured in more detail by using this technique.

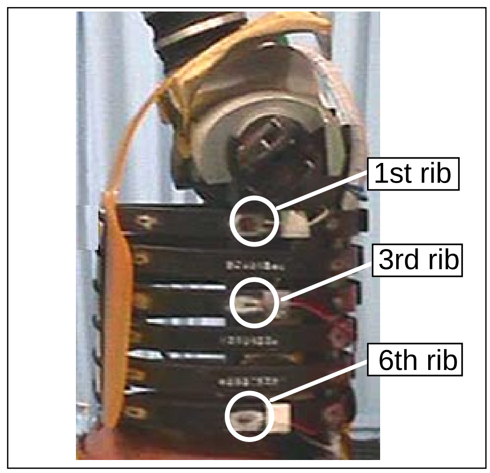


Fig. 7 Strain gauge locations

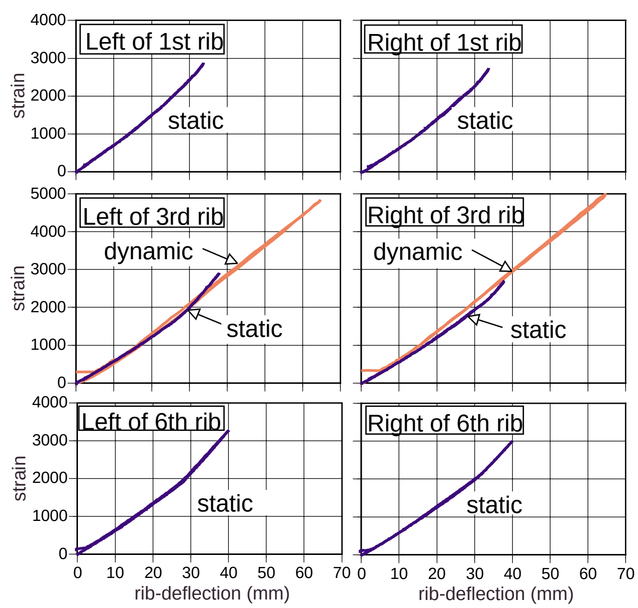


Fig. 8 Results of calibration tests

3.2 Dummy sternum characteristics upon steering wheel contact

To examine the dummy sternum characteristic when the steering wheel makes contact, impact tests with Hybrid-III were conducted (Figure 9). In this test, a rigid impactor, whose tip replicates the steering wheel rim, impacts the sternum of the dummy in a driving posture. Three contact points were selected: the first rib, third rib, and sixth rib.

Figure 10 shows one example of a test result. The waveform of the chest displacement meter corresponds to that of the third rib because the meter measures the vicinity of this rib. Moreover, both the right and left waveform in each rib correspond. Therefore, this technique can measure the rib deflection when the steering wheel makes contact.

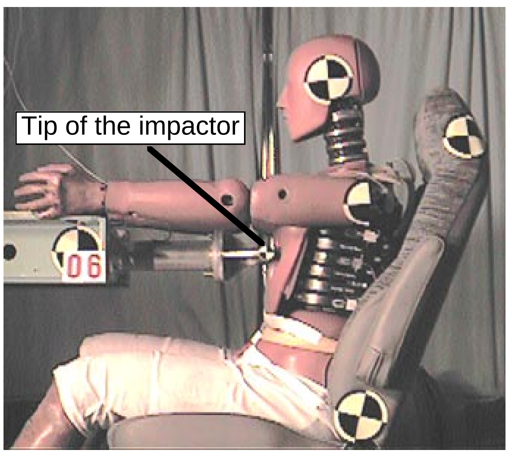


Fig. 9 Situation of the impact test (3rd rib contact)

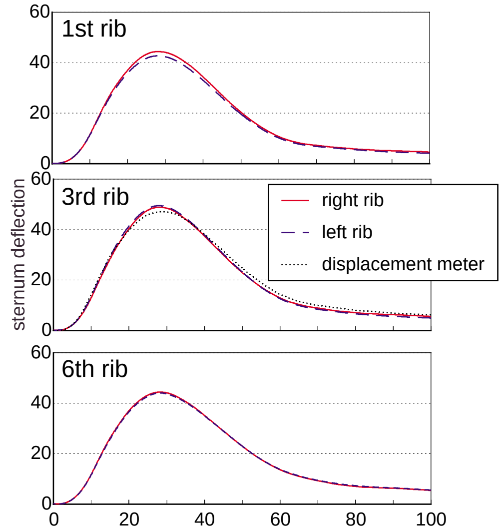


Fig. 10 Sternum deflection - time curve (3rd rib contact)

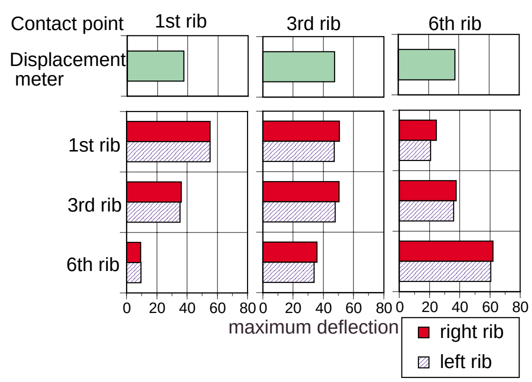


Fig. 11 The relationship between contact point and maximum deflection (Driving posture)

The relationship between contact point and maximum deflection is indicated in Figure 11. When the impactor contacted the third rib, the displacement meter reading was almost the same as for the deflection of the first and third rib. But when the impactor contacted the first rib, the rib deflection level was about 1.5 times that of the displacement meter. In the same way, when the impactor contacted the sixth rib, the rib deflection was about 1.6 times that of the displacement meter.

Under these conditions, when a narrow object like the steering rim contacted the dummy sternum, the rib deflection at the point of contact was largest.

Therefore, it is necessary to measure the deflection of each rib to evaluate sternum injuries by the steering wheel. Moreover, the Viscous Criterion (VC) of each rib can be calculated by measuring each rib deflection. VC is one of the chest injury criteria that is effective in the evaluation of soft tissue injuries[7].

4. Rear-end collision tests with heavy-duty trucks

The deformation of a truck cab and the injury situation of truck drivers were confirmed by reproducing rear-end collisions of heavy-duty trucks through tests in three cases. Figure 12 shows the test method used for rear-end collisions. An object truck traveling at from 35 to 40 km/h was arranged to collide into the rear of a struck truck. A Hybrid-III dummy was belted to the driver's seat of the

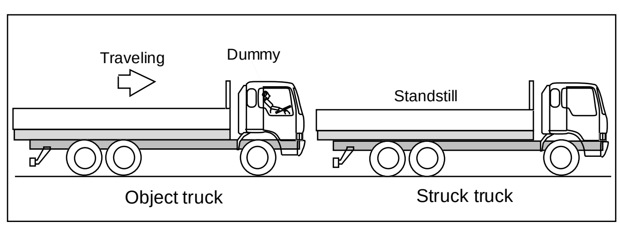


Fig. 12 Test method for rear-end collision

object truck, and the rib deflection was measured along with other values with the usual meters mentioned above.

Figure 13 shows an example of the truck cab deformation around the driver's seat. The displacement in front of the cab reaches the level at which the truck driver presumably sustains serious injury. The steering wheel moves vertically upward, and the seat installation area falls forward.

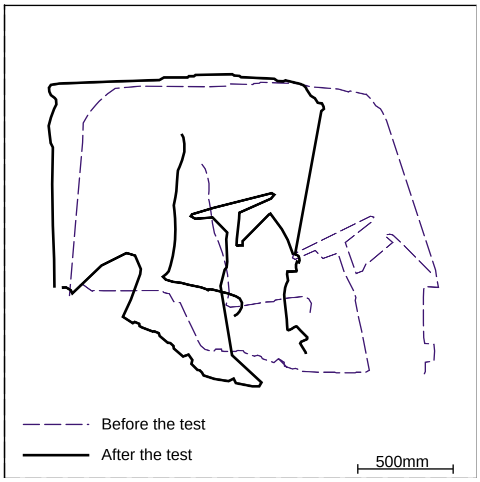
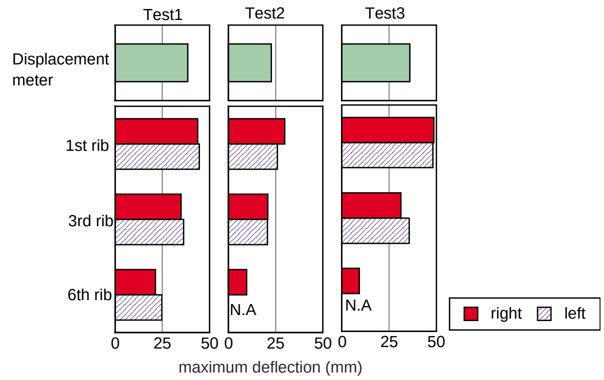


Fig. 13 Truck cab deformation around driver's seat

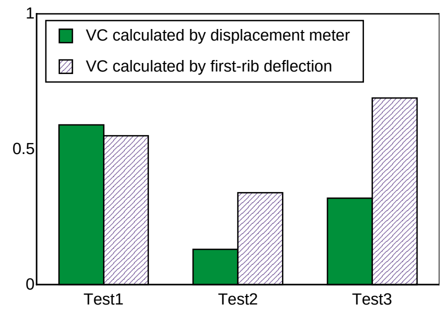
The chest on the driver dummy is crushed between the steering wheel and the seat, as is the waist from knees to hips between the instrument panel and the seat. Thus, the driver would presumably be trapped and unable to extricate himself on his own.

As for the injury criteria for the dummy, the HIC and chest acceleration were lower than in the test result based on the guidelines, whereas the femur load was higher than the test result based on these guidelines. One factor explaining this difference would be that in our testing the test conditions called for lower acceleration but higher truck cab deformation than used in the guidelines.

The results of the deflection and VC satisfied both criteria (chest deflection<76 mm prescribed by FMVSS208 , VC<1.0 m/s prescribed by ECE), because an energy-absorbing steering wheel etc. was employed (Figure 14). The first-rib deflection of each test, however, was the largest in terms of sternum deflection. Thus, the displacement meter value was small in comparison with the first-rib deflection. VC calculated by the displacement meter virtually corresponds to the VC calculated for the first-rib deflection in Test 1. But the VC calculated by the displacement meter was smaller than the one calculated for first-rib deflection in Test 2 and Test 3.



(a) Deflection of the sternum



(b) VC of the sternum

Fig. 14 The results of the chest criteria of the truck driver

The deflection and VC of the first rib tended to show higher values for each rib. In these tests, to obtain more detailed information on sternum injury, the deflection of each rib must be measured in the Hybrid III upon contact with the steering wheel.

5. Driver rescue performance in heavy-duty trucks

To improve the rescue performance for a truck driver in a frontal collision, it is preferable to consider a vehicle structure in which the driver would not be trapped and could escape by himself. Nevertheless, it would be virtually impossible to envisage a construction that would allow escape from the cab in every kind of accident.

The driver is usually rescued by a rescue team in an accident in which the truck driver is trapped in the truck cab. Thus, ways to improve the rescue procedure were investigated by interviewing rescue teams.

5.1 Rescue method

When a driver is trapped in the truck cab, a rescue team is mobilized and sent to the scene at once with a rescue vehicle well equipped with rescue equipment (e.g., hydraulic spreader and hydraulic cutter shown in Figure 15).

A general rescue plan for a truck driver trapped in a cab is as follows.

1) Condition confirmation

The condition of the injured driver and trapped situation are confirmed. The location where the driver is pinned is also confirmed.

2) Separation of vehicles

The crashed truck is separated from the partner vehicle using the rescue vehicle. At the same time, emergency treatment is given to the driver. Fire extinguishers are on the ready to extinguish a possible vehicle fire.

3) Door opening

In frontal collisions, the door can not be opened, so it must be removed to create an escape passage for the driver.

At first, the door hinge is cut with the cutter. Next, the door post is cut, and the door is removed. If the edge of cutter can not be inserted to cut post, the door frame around the post must be forced open using the spreader etc.

(a) Hydraulic spreader

(b) Hydraulic cutter
Fig. 15 Rescue tools

4) Survival space

If the driver is caught between the seat and front panels, an opening is needed to extricate him. At first, the bottom of A-pillar is cut using the cutter. Next, a cable is wound around the steering column and/or instrument panel. Then, a winch is used to free the driver. At the same time, the leg area is expanded using the spreader.

5) Rescue of driver

The lower part of the driver's body is pulled out on the seat, placed on a stretcher and lifted out of the truck.

The average time required for such rescue activity (process from arrival at scene to end of rescue work) is presumed to be about 20-30 minutes. However, the rescue may take longer depending on the situation.

5.2 Cab construction customized for rescue performance

For better rescue performance, the following improvements were desirable .

1) Improved door frame construction

The door opening must allow the edge of the spreader (cutter) to be inserted. Thus, the door frame construction must be highly resistant to crushing. With the recent development of new rescue equipment, rescue performance is steadily improving.

2) Improved front panels

Extrication might be delayed because the rescue team is unfamiliar with the details of the cab structure, and there is no hole to allow cable insertion in the front of the cab. Therefore, technical exchanges between engineers of truck manufactures and rescue teams are desireble. Truck manufacturers must consider truck designs that will enhance rescue performance.

3) Instrument panel improvements

To make room to free the legs, the spreader requires a fulcrum. However, plastic/resin materials used for instrument panels snap under heavy loads. Thus, some point behind the panel must be provided to serve as a fulcrum for such loads.

Similar problems were reported in rescue activity in Germany [8]. In addition, conventional rescue equipment can no longer be used because the cab structure has been reinforced so as to comply with ECE29 regulations adopted in Europe.

In the light of the foregoing, it is desirable to improve rescue performance along with the safety of large trucks, taking safety precautions and duly enhancing safety in collisions.

6. Summary

The results obtained from the present study are summarized as follows.

(1) The sternum deflection can be determined in more detail by measuring the strain of each rib.
(2) It is necessary to measure the deflection of each rib to evaluate sternum injuries by the steering wheel.
(3) The danger is that the driver might be trapped and unable to extricate himself due to the frontal deformation of the truck cab.
(4) To improve the safety of heavy-duty trucks, in addition to improving active safety and passive safety, rescue performance must be upgraded.

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