Frontal Collision Safety of Bus Passengers in Japan

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Paper Number 363

ABSTRACT

Recently, the crash-safety measures against the bus crew and the passengers came to be requested by the rise of demands for the crash-safety performances of automobiles.
In Japan, the guideline for the bus crash test was worked out in 1999. We started the research for the further safety of bus passengers. We are examining the bus crash safety which considers the actual situation of the bus where the seat belt wearing is not obligation for bus passengers. Sled tests of which the test parameters were seat belt, seat interval, and posture, etc. were done, the following conclusions are proposed.
The first row passenger: Three point seat belt effectiveness.
The second row and further back passenger: Improvement of two point seat belt effectiveness.
In this report, the test results, the consideration result of the current standard seen from the viewpoint of international harmonization, and the current research activities are described.

1. INTRODUCTION

Japan faces a grim situation in which approximately 9,000 persons are killed yearly in traffic accidents. Investigations of safety measures to reduce the number of fatalities are currently moving ahead in many quarters [1]. Recently, the primary focus to improve bus safety in Japan has been crash-safety measures for passengers in frontal collisions. In 1997, the guidelines were worked out to measure quantitatively the effectiveness of passenger protection measures for a large bus by crash testing [2].
Currently, we are working on passenger protection, focusing on the installation of various equipments attached to the seat and seat back. Some parts of our study were presented in 2001 ESV [3].
Here we report the current problem and measures based on sled-impact experiments simulating the bus passenger seat as a result after that, as well as coordination trends and problems for international and Japanese standards.

2. BUS ACCIDENTS IN JAPAN

In Japan, head-on and rear-end collision accounts for 67% of the serious accidents involving large buses. Most injured passengers seated in the first row were injured by the partition. Furthermore, around 50% of the passengers seated in the second and subsequent rows were injured by hitting the seat back in the row in front of them [4]. In Japan, bus passengers are not legally required to wear seat belts. The seat belt utilization rate probably does not exceed 10%, although there is no data to quantify the seat belt utilization by bus passenger in Japan.
We must therefore assume such a utilization rate to examine the bus occupant protection during accidents in Japan.
To examine accident injuries based on the current seat-belt utilization, we conducted a sled test that simulated the bus passenger seat. The test results indicated that further seat-belt improvement is necessary. We examined crash safety with regard to such improvements and report the results in the following.

3. SLED IMPACT TESTING

3.1 Sled test method

In the tests, a sled simulating a bus passenger cabin (see Fig. 1; partition, service box, and first- and second-row seats) is launched at high speed, and the force of impact on various parts of seated dummies (Hybrid-III) is measured. The sled-launching curve is a guideline related to collision testing that Japan has developed (delta-V, a 35 km/h, full-wrap frontal impact). The test parameter are type of seat, seat belt, seat-belt anchor position, seating posture and seat belt type (see Table 1). In addition, we examined ECE R80 [5] from the viewpoint of international standardization by sled impact testing.

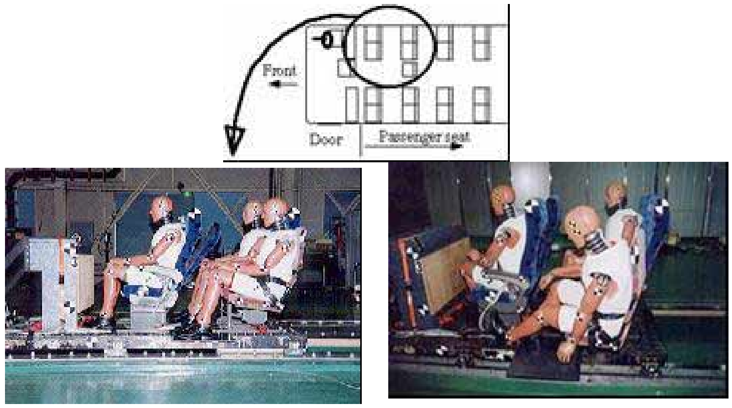


Figure 1. Test situation

Table 1. Test parameters

Test parameter	
velocity (delta-V)	35km/h (guideline), 32km/h (ECE R80)
seat belt type	2-point ELR, 2-point fixing, 3-point ELR
seat belt anchor position	standard (60deg.), modify (45drg.)
seating position	first-row, second-row, auxiliary seat
seating posture	normal, safty

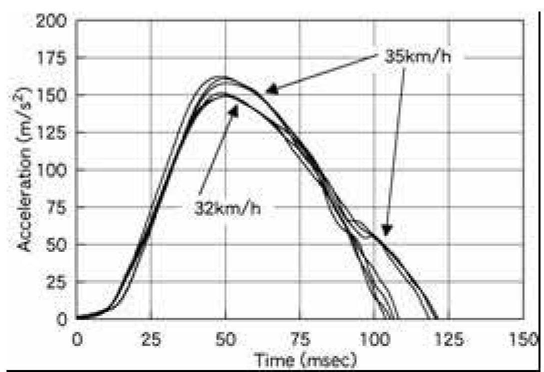


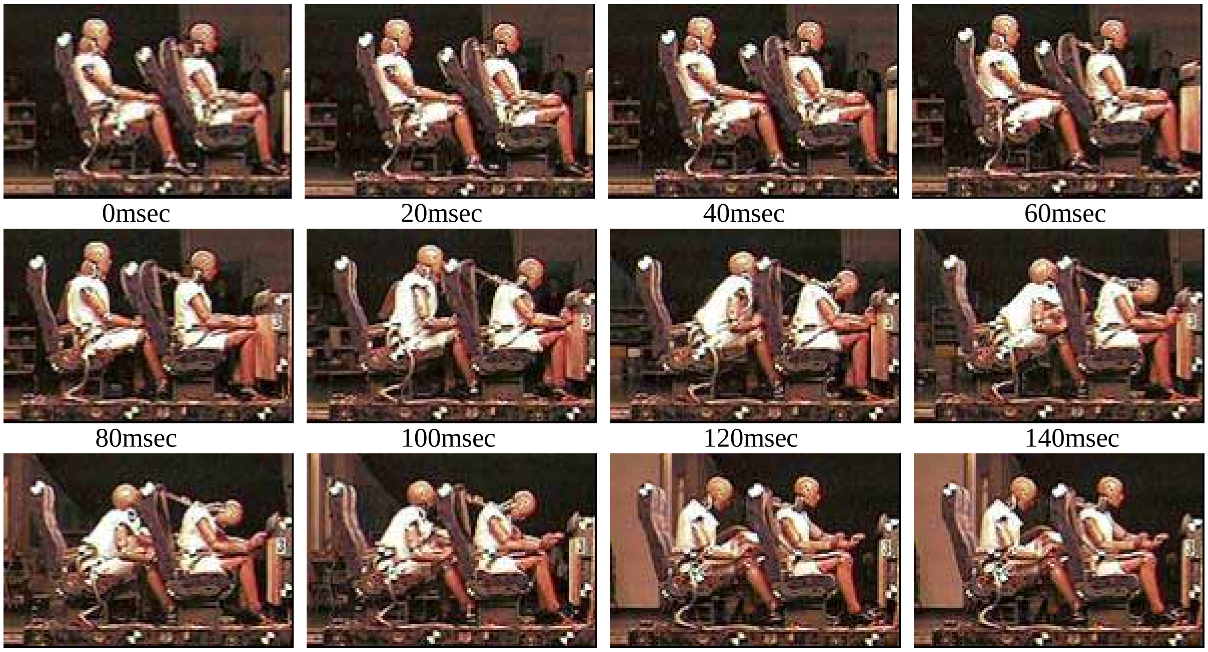
Figure 2. Sled acceleration curves

<u>3.2 Experiment results</u>

Figure 2 shows the acceleration curve of the sled.

The acceleration curve for ECE R80 is somewhat more severer than the regulation acceleration corridor. However, the speed difference before and after the collision (delta V) was assumed to be 32 km/h, the same as for the ECE R80 standard.

Figure 3 shows one example of the dummy behavior captured by high-speed video camera.



0msec 20msec 40msec 60msec
80msec 100msec 120msec 140msec
160msec 180msec 200msec 220msec

Figure 3. Example of dummy behavior

(a) normal (b) safety (second row) (c) safety (first row)

Figure 4. Seating posture

In the test, the sled is launched from the right side of the photograph and travels to the left side. The dummy in the first row (right side of the photograph) is wearing a three-point ELR seat belt wearing in the standard posture. The passenger on this side of the second row (left of the photograph) lowered the seat back of the front seat to a reclining position and is wearing a standard ELR two-point seat belt in the standard posture. The passenger further away is seated in an assistance seat peculiar to Japan and is wearing a two-point fixed seat belt. The seat interval is assumed to be 860mm. Seating posture is shown in figure 4.

The current seat belt anchor position is 45 degrees from the H-point and rotates 60 degrees from the H-point (see Figure 5).

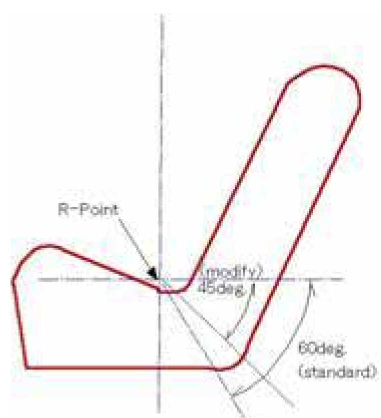


Figure 5. Seat belt anchor position

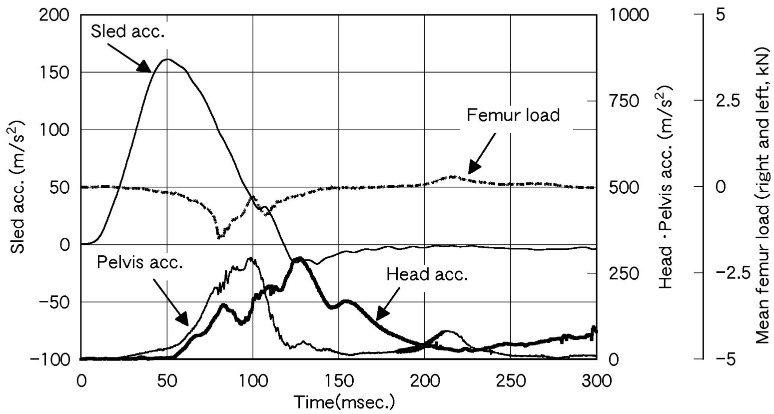


Figure 6. Example of electrical response data

Figure 6 shows the electrical response data for each part of the dummy at the time measured in Figure 3 (first row dummy; wearing three-point ELR seat belt).

The acceleration of the head begins to rise after about 25msec. About 25msec after the sled launch, the femur load is negative due to inertia force. A high peak load due to compressive force has not yet been generated because the femur does not collide with the partition until later.

3.3 Current occupant protection

The injury severity based on the current two-point seat belt is plotted in a radar chart and shows in Figure 7.

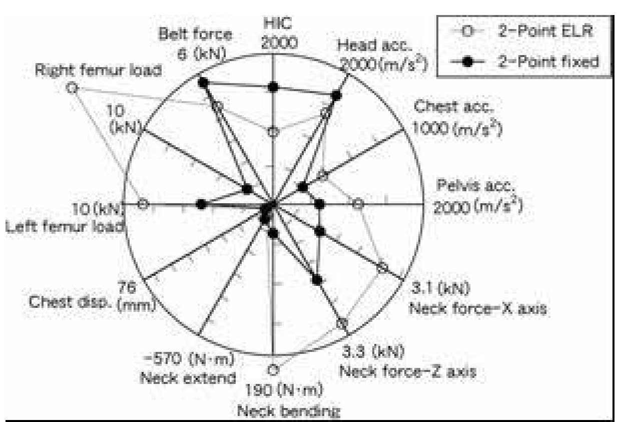


Figure 7. Comparison of HIC and maximum values according to 2-point seat belt type (first-row occupant)

The HIC value of the passenger wearing the two-point fixed type seat belt in the first row is especially high. This shows that the protection when the head collides is insufficient (depending on the dummy behavior), even though a protection pad has been added to the partition.

3.4 Seating posture

The injury severity when the occupant takes the safety posture based on the current two-point seat belt is plotted in a radar chart and shows in Figure 8.

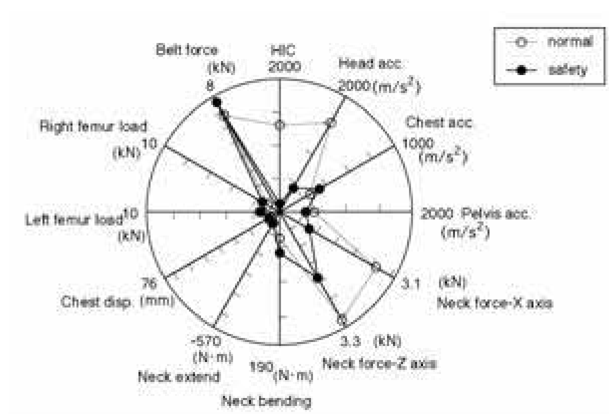


Figure 8. Comparison of HIC and maximum values classified by sit-down posture (second -row occupant)

HIC and injury values have become small by taking the safety posture. Therefore, the safety posture is effective to the injury reduction for two point seat belt. In Japan, the bus passenger does not have the obligation that the seat belt wears. We think the energy-absorption in the seat back of the front seat to be important about the non-belted passenger. Therefore, we think that the effectiveness improvement of two point seat belt is also important. It has been understood that the safety posture is effective to the improvement of the effectiveness of two point seat belt.

3.5 Investigation of seat-belt improvement

The injury ratings of the dummy when a three-point seat belt is used for the first row are plotted in a radar chart and shown Figure 9.

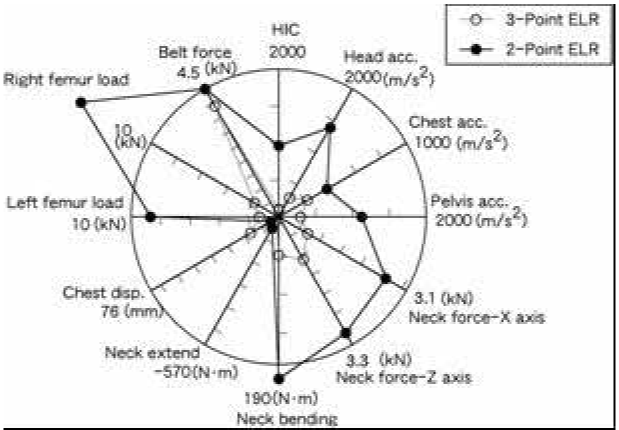


Figure 9. Comparison of HIC and the maximum values when wearing the 3- point seat belt and 2-point seat belt (first-row occupant)

Use of a three-point seat belt prevents head collision with the partition for first-row passengers, and HIC decreases.

Next, the injury ratings for second-row occupants wearing a two-point seat belt with a different seat belt anchor position, the present two-point seat belt, and a three-point seat belt are plotted in a radar chart and shown in Figure 10.

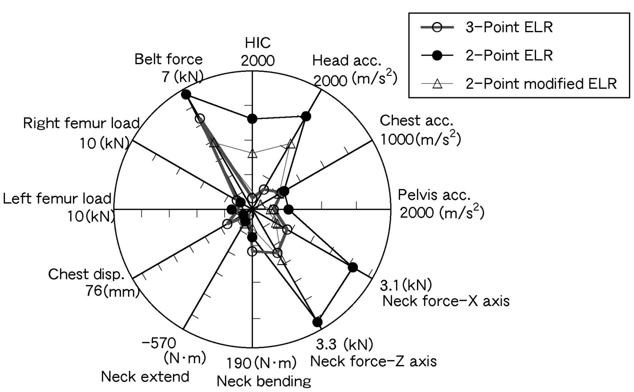


Figure10. Comparison of HIC and the maximum values for 2-point seat belt anchor position etc. (second-row occupant)

Wearing a three-point seat belt reduces the head injury of the second-row passenger. However, a two-point seat belt with a different seat belt anchor position is an effective second row seat restraint system. We think that the occupant protection improves because changing the seat belt anchor position increases the seat belt effectiveness. Then, we want to adopt two-point seat belt, considering the seat belt wearing situation etc. in the second or subsequent rows.

The protection of seat-belt wearing occupants is improved based on the experimental result as follows.

For first-row passengers, install and use a three-point seat belt.

For passengers seated in the second or subsequent rows, improve protection by modifying the two-point seat belt anchor position.

In addition, when colliding, the safety posture increases the effectiveness of the seat belt.

4. STUDY FOR INTERNATIONAL HARMONIZATION

ECE R14 has been accepted for regulation in Japan to support international harmonization. Three-point seat belts must therefore be installed in buses. However, bus passengers in Japan are not required to wear seat belts. Therefore, protective measures based only on seat belts are not enough. Adopting energy-absorption devices such as seat backs in the row in front is important for bus passenger safety. Based on the sled test, a three-point seat belt should be installed for passengers in the first row, and an improved two-point seat belt should be installed for passengers in the second and subsequent rows. ECE R80 and ECE R14 should thus be adopted.

Here, ECE R14 and the Japanese regulation, which is the standard for bus seat belt anchors, are compared in Table 2.

Table 2 Comparison of ECE R14 and the Japanese regulation

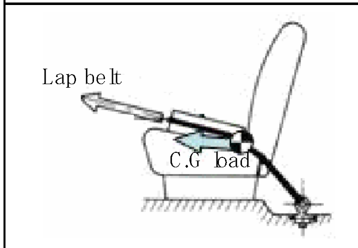
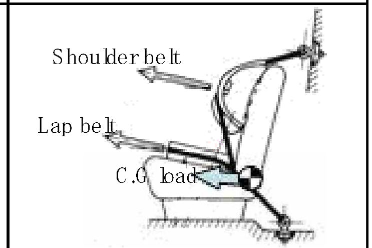
	2-Point		3-Point	
Belt type				
	ECE R14	Japan	ECE R14	Japan
Lap belt	7400±200N	2940N	4500±200N	2940N
Shoulder belt			4500±200N	2940N
C.G load	M×6.6	(35+M/2)*4N	M×6.6	(35+M/2)*4N

Table 3 Comparison of the ECE R80 dynamic test and the guideline in Japan

	Test condition	Evaluation value		
	Velocity (km/h)	HIC	Chest 3msecG	Femur load (kN)
ECE R80	30 - 32	500	30	5
Guideline	35	1000	60	10
FMVSS 208 etc.	48	1000	60	10

In the sled test, we apply a load of ECE R14 or more to the seat belt anchor for the bus seat; the seat belt anchor was not damaged in the sled test.

Next, the performance requirement for a dynamic test of the ECE R80 and the guideline of the collision test in Japan are compared in Table 3 with respect to bus passenger safety.

The test condition of the guideline is 35 km/h, which corresponds to the 95%ile of the bus accidents in Japan. ECE R80, however, specifies 32 km/h, which is lower than the guideline. The injury criterion of the guideline (HIC, chest acceleration, and femur load) adopts the same rating as general crash test methods such as FMVSS208 [6]. The injury criterion of ECE R80 is half that adopted in general crash test methods. The testing condition and the injury criterion differ in the guideline that Japan formulated and ECE R80. The guideline and ECE R80 must be harmonized for adopting ECE R80. The sled test executed in Japan was based on ECE R80. The present seat satisfies the injury criterion adopted in the guideline. However, the present seat does not satisfy ECE R80 because HIC exceeded the criterion (see Figure 11).

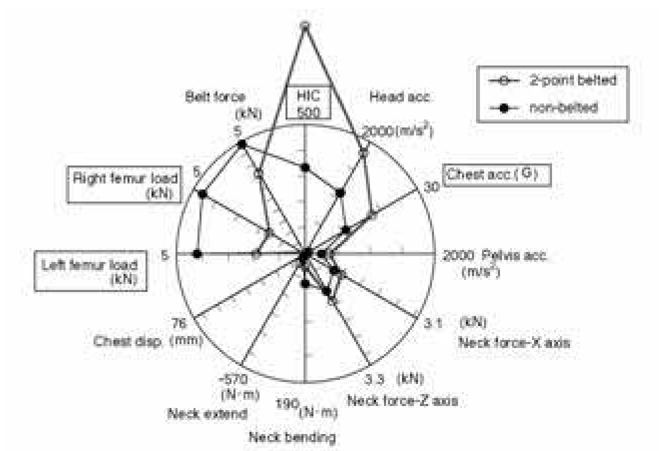


Figure 11. HIC and the maximum values when testing it with ECE R80

HIC is an algorithm (shown in formula 1) that simulates a head tolerance curve [7], and the proportional index of the acceleration of the 2.5th power.

$$HIC = (t_2 - t_1)\left[\frac{1}{(t_2 - t_1)}\int_{t_1}^{t_2} \alpha dt\right]^{2.5} \quad (1)$$

Generally, HIC1000 is assumed to be an index that evaluates the level of the concussion generated. For instance, HIC can be related to the probability of death [8]. HIC is thus an index for which it is dangerous to exceed a certain level (see Figure 12). The level is not HIC 500 but HIC1000.

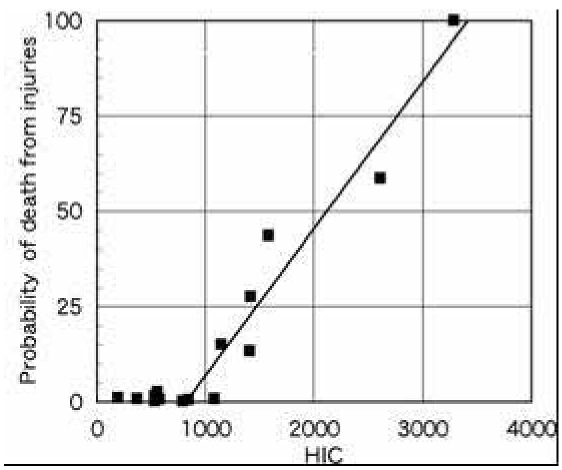


Figure 12. Relation between HIC and the probability of death

Testing conditions corresponding to the 95%ile of bus accidents were established as a guideline, and the possibility of injury is appreciable. The bus passenger injury to which almost all bus accidents are assumed by the criterion of HIC 1000, chest acceleration 60G-3msec, and femur load 10kN is appreciable. On the other hand, it is necessary to clarify the injury level for a range of accident assumptions that can be evaluated based on ECE R80. It is therefore necessary to examine the validity of the testing conditions and the injury evaluation level to adopt ECE R80.

5. SUMMARY

Based on the sled tests simulating the bus passenger seat to improve the safety of bus passengers, it will be useful to study the current bus passenger seat to improve the seat belt.
Future studies will focus on the following.

Seat belt for bus passengers

1) We must adopt a three-point seat belt for first-row passengers to reduce head injuries.
2) We should also optimize the two-point seat belt anchor positions etc. for passengers in the second and subsequent rows.

International harmonization
It is important to advance the harmonization of bus crash-test guidelines and ECE R80, and to consider additional safety requirements for bus passenger safety.
However, it is necessary to reconsider injury criterion such as HIC in ECE R80 considering the human body tolerance.

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