A Study of Passenger's Whiplash Behavior during Rear-end Collision at Low Vehicle Speed

2nd. Report ; Development of a seat to reduce whiplash inpact and maintain appropriate posture

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Abstract

A new sled type collision apparatus was developed, which was able to simulate an actual vehicle rear-end collision. Next, in order to obtain "compressing behavior" as an affecting force to a neck as well as deformation movements of "over-extension" and "shearing", an experiment for rear-end impact was carried out using the sled apparatus, and a collision simulation was also made with a computer program. On the basis of the result and a reference to the users' seat positions of general passenger vehicles, a trial seat was manufactured to enable reduction of whiplash injury. As a result, the occurrence of compression movement along the cervix to the spinal cord was suggested [1]. Consequently, to reduce whiplash injury during rear-end collision at low speed, it is necessary to repress the sharp compressing movement in the neck first, and second, the specific characteristic of the seat, for example, were devised to control the effective temperature that is important for the passenger to maintain appropriate seating posture.

Keywords: Low Speed Collision, Whiplash Injury, Cervix Motion, Comfortable Seat

1. Introduction

Nowadays in Japan, the death toll caused by vehicle traffic accidents is less than 9,000 people a year and shows a slight decrease. This tendency is depending on the effect of the

Received 20 January 2011

progress of "safety technology" and the introduction of "emergency care system". On the contrary the number of people injured by traffic accidents is on the increase. The number of passengers neck injuries occurred by vehicle's rear-end collisions at low speed, i.e. so-called "whiplash injury", is especially high, even though wearing of the head restraint was obliged to since 1970. Recently the existence of the input outer rather than "Over-extension and shearing" is considered as the cause of generating the whiplash damage. For example, the existence of "compressing load input" is reported, and the influence of it is discussed [2],[3]. On the other hand, automobile companies also came to do standard wearing of the seat with the mechanism by which the whiplash damage is reduced [4].

In this study, firstly, experiments of the rear-end collision were carried out using small-sized passenger cars and acceleration patterns were measured while the car was impacting. Subsequently, a new sled type collision apparatus was developed, which was able to simulate the same acceleration pattern of an actual vehicle rear-end collision. Experiments were conducted under the condition of a normal commercial seat and a trial seat manufactured by us using a Hybrid-3 dummy equipped with TRID2-neck. The existence of the compression load acting on its neck was observed, and a computer simulation analysis of the input to the neck was also carried out to compare with experimental test results. The present report discusses, finally, passenger seat characteristics to suppresses "the neck input in a rear-end collision at low speed" and to maintain the appropriate seating posture in respect of effective temperature.

2. Aspect of whiplash injury in japan

Nowadays Since the term of "Whiplash injury of the neck" was introduced to Japan for the first time in 1958, the number of cases reporting a neck sprain is increasing rapidly. In the white paper on traffic safety 2002 in Japan, the number of 1.1 millions people was injured. A lot of "slight injuries" examples that injury in itself in particular seems to be doubted were included in there. It seems to be a problem that many cases are based only on "the own petition". Fig.1 shows the statistic data of the traffic accident in Japan [5]. According to the report published by Insurance Association of Japan, it is reported that 1/3 were the slight whiplash injured among the all casualties by traffic accident [6]. To prevent the increase in the number of whiplash injury, the government went into the examination from 1967 and after that imposed a duty of "standard equipment of head restraint" on passenger cars. Then, it was expected that the number of neck injury would decrease by the existence of head restraint, however, the number of the patients of whiplash injury did not decrease. On the other hand, from the latter period of 1990's, automobile companies came to install a specific seat which was able to reduce the whiplash damage. Its type is roughly divided into two kinds. Fig.2 shows one type in which a head restraint carries out movable [1]. The other type catches shoulders softly as shown in Fig.3. The device is given to the back reclining part of a seat for both of the types.

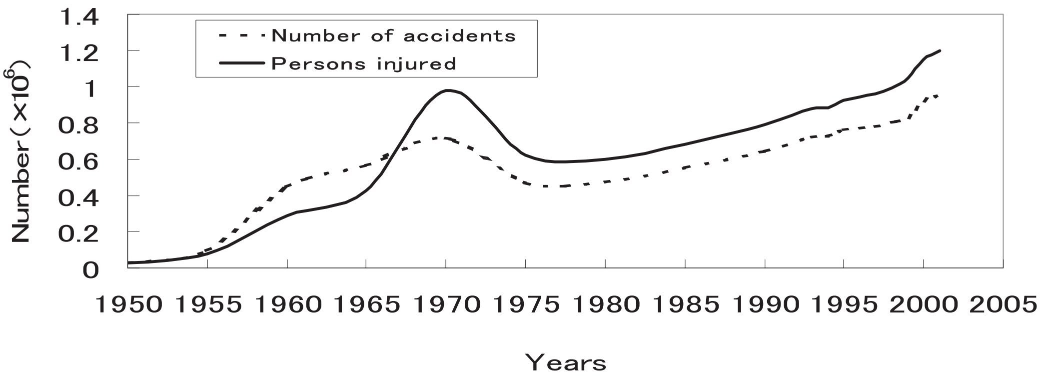


Fig.1 Statistic data of the traffic accident in Japan [4]

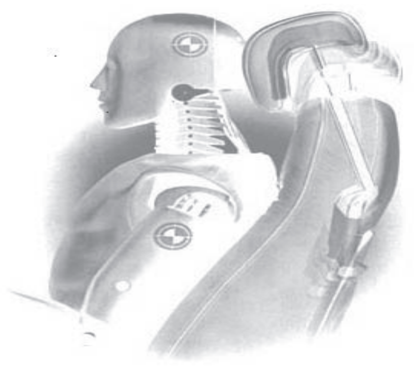


Fig.2 A type of seat in which a head restraint carries out movable

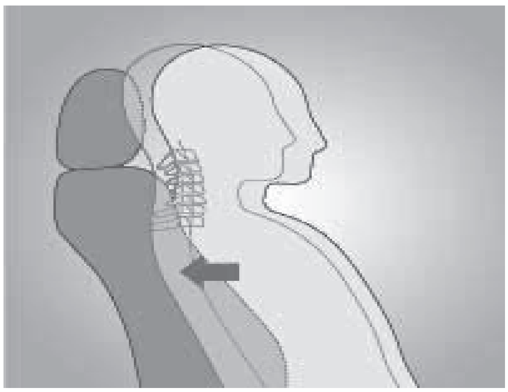


Fig.3 A type of seat that catches shoulder parts softly

3. Vehicle collision test and fundamental data

In this research, firstly, the collision experiment was carried out using small-sized passenger cars. The purpose of this experiment is to obtain an acceleration pattern during collision. Fig.4 shows a schematic diagram of a collision experiment, and vehicles used are the same type. Fig.5 shows an example of the obtained acceleration pattern. In the figure, 'A' is the maximum of the acceleration and 'Δt' is the period while the acceleration is acting.

Fig.6 shows the relation between the collision speed and the maximum acceleration generated on the collided vehicle. Fig.7 shows the relation between the collision speed and the contact time of vehicles. The sled type testing apparatus was manufactured based on these data.

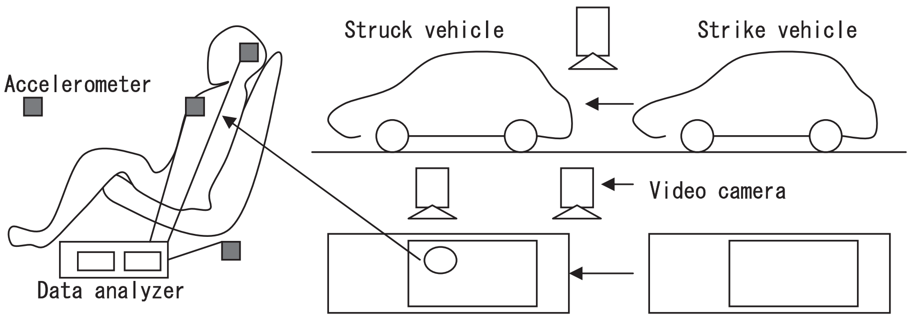


Fig.4 Schematic diagram of collision experiment

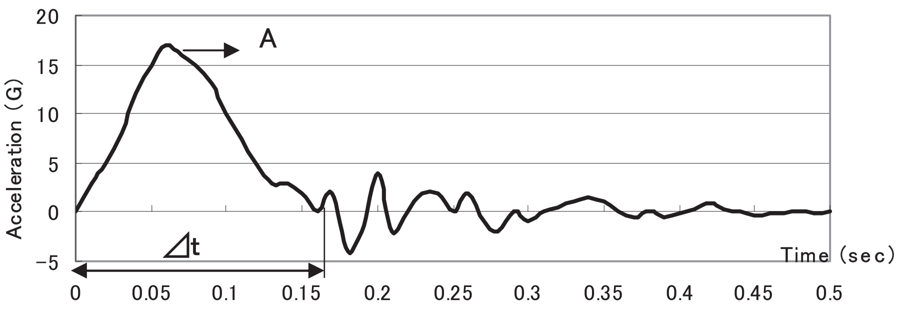


Fig.5. Example of the obtained acceleration pattern

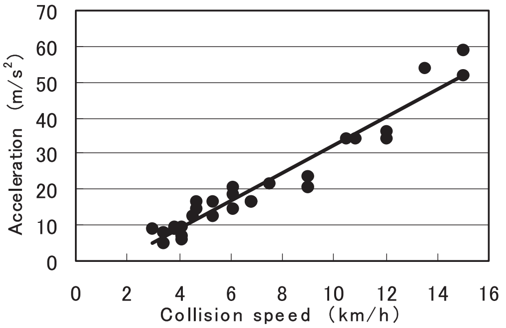


Fig.6 Relation between striking speed and Maximum acceleration of struck vehicle

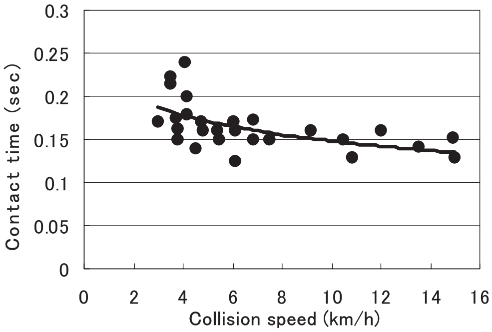


Fig.7 Relation between collision speed and contact time

4. Sled type collision apparatus

Fig.8 shows a schematic diagram of the sled type collision apparatus made as an experiment. The sled, which carried a subject passenger on the seat, is driven by leading rope succeeded to the falling gravity weight.

Hereafter, an experiment procedure is explained. The acceleration obtained here is a negative value.

1) The collision speed is set up by changing the quantity of weight or fall height.
2) The weight is dropped and the sled is accelerated along the horizontal rails.
3) The leading rope is automatically released at 0.5m point just before a collision.

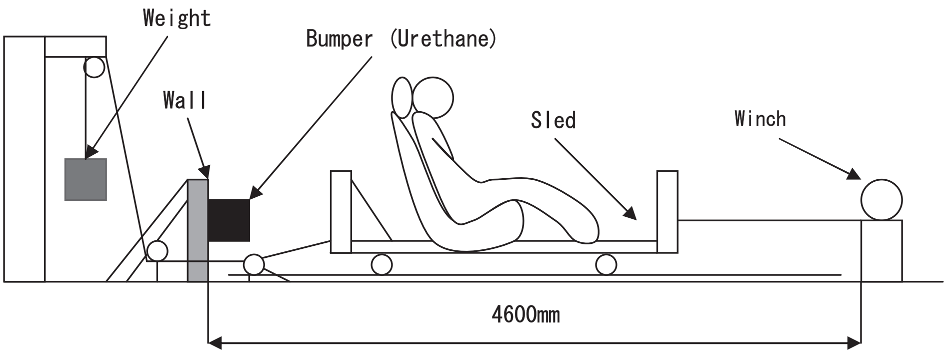


Fig.8 Schematic diagram of the sled type collision apparatus

The sled acceleration just before a collision is a state of 0 with the above-mentioned procedure. It is important that the acceleration pattern on the sled apparatus should be simulated as same as one during an actual vehicle collision. Therefore, various materials and various shapes of the bumper were used and were examined. As a result, "a kind of hard urethane" was adopted as a material of the bumper and an acceleration pattern was obtained by adjusting numbers of sheets. Fig.9 shows the side view of the sled apparatus and the accelerometers set on each (a) ~ (d) location. Acceleration patterns measured on the sled apparatus are shown in Fig.10 comparing with ones on the actual vehicle. The similarity between both acceleration curves is recognized. In this figure, the sled acceleration pattern is reversing positive to negative.

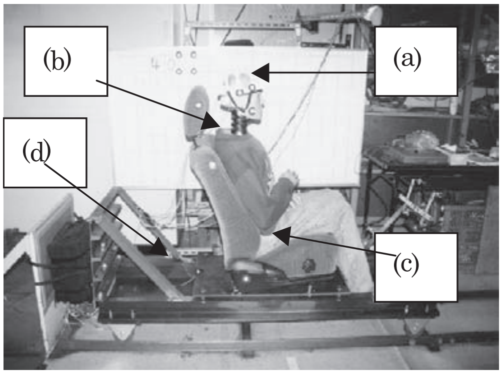


Fig.9 Sled view and the part equipped with the accelerometer

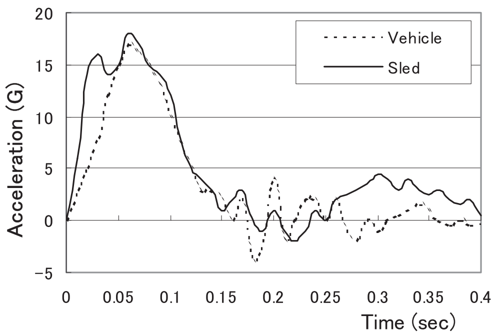


Fig.10 Acceleration patterns of an actual vehicle and a sled

5. Experimental results

Collision experiments were conducted using the sled apparatus at speed of 3 to 7 km/h. Acceleration values at several parts of the dummy passenger were measured by accelerometers, and force values loading at its neck were obtained with specific load transducers. The dummy's behavior was also caught by a high-speed VTR camera.

5.1 Observation of the high-speed video image

As the presence of "over-extension" and the "shearing" behaviors on the neck is known well, we here paid our attentions to the "compression behavior of neck".

Several markers were stuck on each part of the dummy to observe these movements as shown in Fig.10. In addition, in conformity with the Helsinki dedication, some subjects volunteers also participated in this experiment. Since the observation result has not extracted the data which can be grasped quantitatively, hereafter, qualitative explanation is described. First, in the case of a volunteer, it was observed that his neck bottom was carried up vertically in comparing with other parts at speed of 6 km/h of the sled.

From the observation result we recognized the relationship between the upper half of the body and the back reclining part of a seat, that is, the shoulder part has obviously sank in a seat back reclining part and subsequently has moved upwards along with it. Next, in the case of a Hybrid3 dummy with TRID-2 neck, less motion in comparison with the volunteer's one was observed since its neck and other parts were still hard together. Therefore, in the experiment using the dummy, the measurements of input terms (acceleration, load et al) on the neck should be needed to grasp the neck deformation behavior.

5.2 Measurement results of the acceleration

Accelerations at each part of the upper half of the body were measured using the accelerometers respectively. Fig.11 shows an example of the acceleration change at speed of 7 km/h. In order to compare with the rear-end collision, here the horizontal acceleration value has alternated positive to negative.

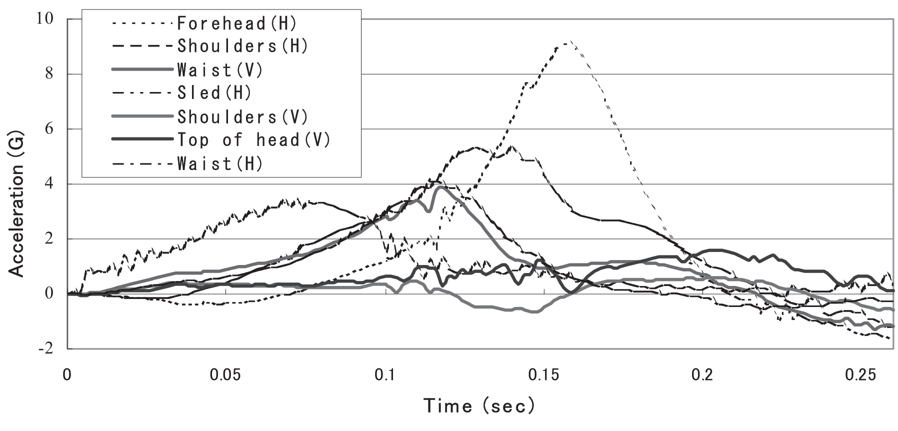


Fig.11 An example of acceleration behaviors obtained at 7 km/h

First, we have paid our attentions to the horizontal value of acceleration, and it is observed that the acceleration value of the forehead part has risen rapidly. This reveals that the back of the head has collided to the headrest. Subsequently, in paying an attention to the both acceleration peak values of the shoulders and the forehead, a time lag is observed. This time lag decreases in accordance with the fall of the sled speed. An important point is that the time lag has occurred just before the back of the head collides to the head restraint obviously. Existence of the time lag has proved that "shearing force" is acting on the neck. Next, in paying an attention to the vertical acceleration value, it is observed that large acceleration is acting on the waist upward. The tendency of this acceleration generation is presumed that the compression load is acting on the neck actually.

5.3 Measurement results of the input components to the neck

A moment of force (My), a shearing force (Fx) and a compression load (Fz), that act on the neck, were measured by the 3-components load cell.

Fig.12 shows an example at speed of 7 km/h of the sled. First, in noticing the compression load value, it took about 0.12 seconds after colliding of the sled to colliding of the head back to the headrest, and it is observed that the both rises of the moment of force and the shearing force have stopped at this point. On the contrary, the compression load has started to rise rapidly.

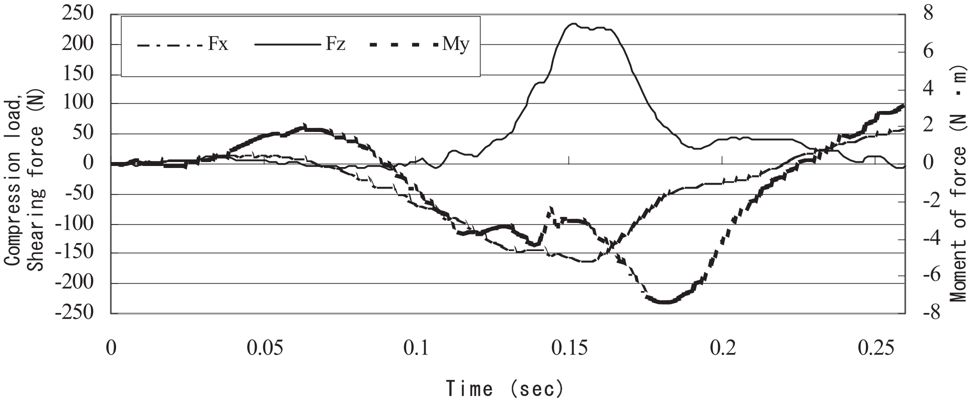


Fig.12 An example of the data obtained by the 3-components load cell at speed of 7 km/h of the sled

5.4 Discussion from measurement results

In this experiment a conventional seat was used, which was equipped with a commercial small-sized passenger car as the driver's seat. It was presumed that collision speed became so high that the stroke of seat back was not sufficient as the result of the experiment.

As far as this experiment is concerned, the neck damage under the condition of such a low speed is so slight that, it is thought, any remarkable problems have not happened. However, in many cases of the rear-end collision accident, any troubles has occurred within such region of low speed. Because it is thought that the diagnosis level of the neck damage depends on only passenger's own petition in case of accidents of this speed range. As the result of experimental data, a possibility such as compressing and shearing deformation would arise almost simultaneously from the spinal cord to the cervix was suggested, but the displacement of each cervical vertebra was not. Then, simple computer simulation was adopted and was tried to examine the deformation behavior of the neck as follows.

6. Simple computer simulation

The computer simulation soft used here is MSC. Working Model for 2D. The simple rigid body was introduced as 2 DM model.

Fig.13 shows a model that simulates a simple actual vehicle collision. The spring equivalent to a bumper is set up so that the contact time may become about 0.15 seconds. The neck is divided into seven cervical vertebras expressed with the rectangular parallelepiped. In order to grasp the shearing deformation of each cervical vertebra, a frictional force was only set up in each rigid body. In addition, the slope of the seat back was set as about 20 degrees. As the result of calculation, under the condition at the speed of about 7 km/h, just after the

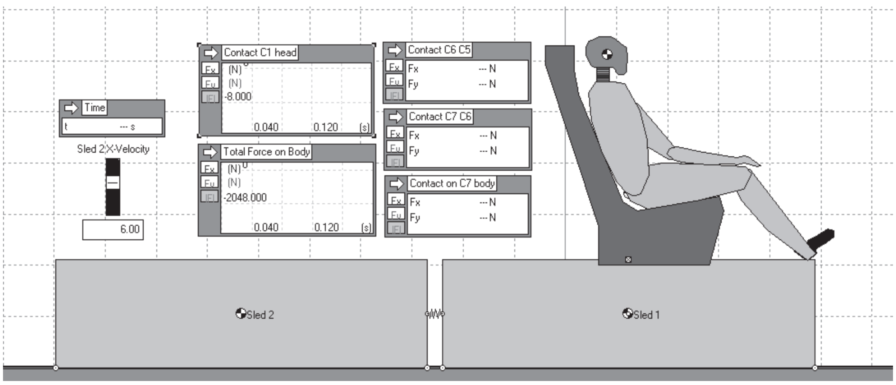
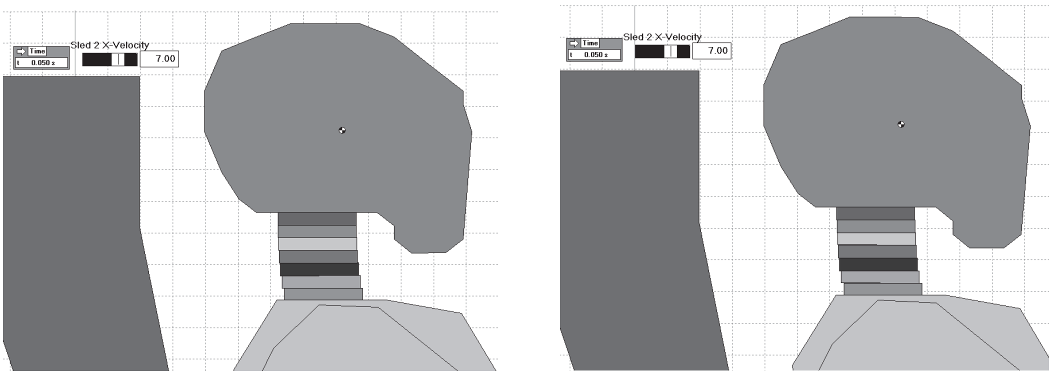


Fig.13 A model which simulates the simple actual vehicle collision

compressing movement appeared at the cervix, a sharp increase of the contact force was observed between the sixth and the seventh of cervical vertebra. Fig.14 shows deformation patterns of the neck. a) is an example in case that the body is not restrained, and on the other hand, b) is being fixed to the seat. In comparison between 2 figures, it is observed that the shearing deformation is concentrating on the neck bottom in A) rather than B). Therefore, the compressing movement in the neck was presumed to encourage the shearing movement and to lead to the sprain of the cervix that made a rather light “whiplash injury”. However, since it is simple setting conditions strictly, a more detailed examination is due to be carried out in the near future.



a) An example in case that the body is not restrained **b) An example of fixed to the seat**

Fig.14 Deformation patterns of the neck

7. Our proposal seat for reducing whiplash input

“Whiplash damage reducing seats (acronym after: WDRS)” are researched and developed by many automobile companies and some of them are already installed in some passenger cars as standard specification. We have also made effort to develop a sort of WDRS and have already manufactured a specific WDRS to enable to reduce whiplash injury on the basis of our experimental results and an investigation data of users’ seat positions in general passenger vehicles.

7.1 Purpose of our proposal WDRS

Some model WDRS were made and were examined on their effects of reducing the neck damage through the experiment of a rear-end collision. With the aim of manufacturing the WDRS, "reduction of input impact to the neck" and "improvement in the sitting comfortability" were considered.

7.2 Examples of the WDRS

It was found that measures to restrain the compressing movement and to sift the timing of each movement occurrence were effective to reduce the whiplash motion of the neck because of the experiment results.

Then, a technique of setting the seat back softly was adopted in this research as shown in Fig.3. The spring characteristic of the seat back was examined in advance before the trial production. The spring characteristic needs the effect of reducing compression load, so that the softer one is required because a passenger body can be caught softly and its rebound can be suppressed. However, the capability of supporting the body gives a limit in the spring softness. Then, a mechanism of stopping the rebound was adopted. The mechanism consists of a lock element to act on in the case when the seat support moved to backward and operates such as a door catch when the stroke beyond a setup arises in the seat back part.

As the effect of reducing the neck shearing motion was recognized experimentally, this concept was adopted in the next trial seat production. An urethane material having a low rebound elasticity was used as the seat cushion parts to stop the rebound. This trial manufactured seat was installed in a commercial small-sized passenger car.

Fig.15 (a) shows the back part of the trial manufactured seat. Fig.15 (b) shows the arrangement of the urethane parts, so that the vertical movement of the passenger's body may be suppressed. This arranging construction is also included both air breathing and the pumping effects. In addition, this effect will be described in a following chapter.

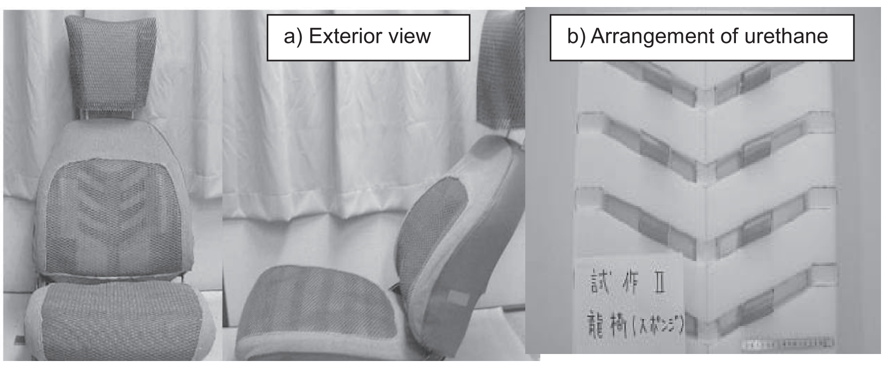


Fig.15 View of the back of the proposal seat

7.3 Results of collision experiments

The effect of reducing on the neck input was compared between the trial manufactured seat and the commercial seat (named WIL seat) with lessening performance of a whiplash injury through collision experiments.

Fig.16 shows an example of the acceleration change obtained in a collision test at speed of 7 km/h. In addition, in order to compare with actual accidents, horizontal acceleration has sifted positive to negative.

Fig. 17 shows the moment and the force values , which were measured by the 3-components load cell in a collision test at speed of 7 km/h.

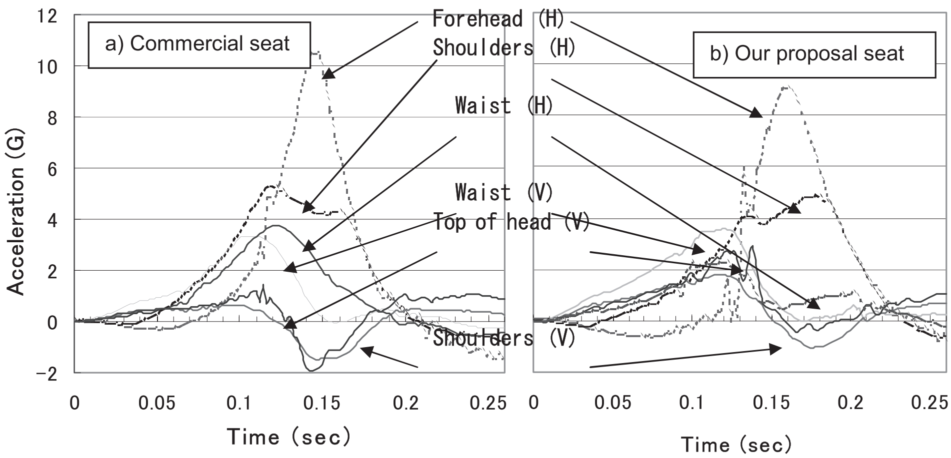


Fig.16 Examples of acceleration changes obtained in a collision test at speed of 7 km/h

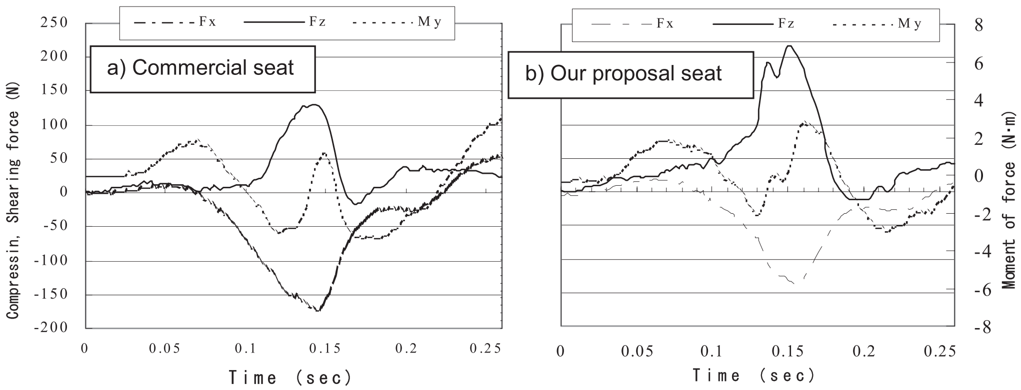


Fig.17 An example of 3-components load cell values obtained at 7 km/h

7.4 Discussion of the proposal seat by measurement results

The data of acceleration and moment and force components with respect to a general commercial seat was shown in Fig. 11 and 12. There were some differences between these data and the data of our proposal seat, however, almost same inclination was observed between our proposal seat and WIL seat.

First, there are few differences between the acceleration of a waist and the top of head in the case of the proposal seat in respect of vertical acceleration changes. It means that the body and the head are moving up and down almost simultaneously. Secondly, for values measured by the 3-compenents load cell, it is seen that the peak value of compression load in the proposal seat was conversely higher. This value occurs just after the back of the head collided to the head restraint, and suggests importance of a headrest design. However, in case of the proposal seat, a moderate compression movement in the neck was observed.

Next, as to the horizontal action, the acceleration of a forehead has risen rapidly in case of the proposal seat, and moreover, this rapid rising and the value of compression load are relevant. In addition, through all experiments, the shearing force to the neck was smaller at peak value in case of the trial production seat. Furthermore, through experimental results, it is suggested that the characteristic of a seat surface of which a backrest part is hard to slide and a headrest is easy to slide is effective in order to decrease compression load to the neck.

If it is assumed that the slight whiplash damage arises mainly by the shearing deformation among cervical vertebrae, a measure to restrain the compressing movement and to sift the timing of each movement occurrence must be introduced to the vehicle seat in order to reduce the whiplash injury in the low speed collision.

8. Measurement of The Effective Temperature In Seating Posture

Even if it is no matter how superior WDRS, we think that it is meaningless if the right taking-a -seat posture is not maintainable, and therefore the measurement was accomplished by this point of view.

From a questionnaire survey, a temperature change to occur between a body and seats as one of the reason why the passenger cannot maintain right posture was given. Then, the arranging construction of our proposal seat was also included both air breathing and the pumping effects.

8.1 Mechanism of our breathing seat

There are patents already as for the device to keep the surface temperature of a seat comfortably by "air breathing", and some automobile manufactures mount a high quality car with a cool and warm air ventilated seat. Therefore, in this study, we did it with the aim of developing a comfortable seat having simple structure. We describe it with "self-breathing seat" here.

Fig.18 shows the pumping mechanism for self-breathing. A lot of small vinyl pipes (about a diameter of 10mm, about 30mm long) are spread to a contact surface of a seat, and each vinyl pipe is made to change into a radius direction and invents a pump effect. This brief pump cycles the inside and peripheral air by the movement of a passenger to occur with top and bottom vibration of a car. It was hoped that the temperature of seating surface neared the body heat by this circulation.

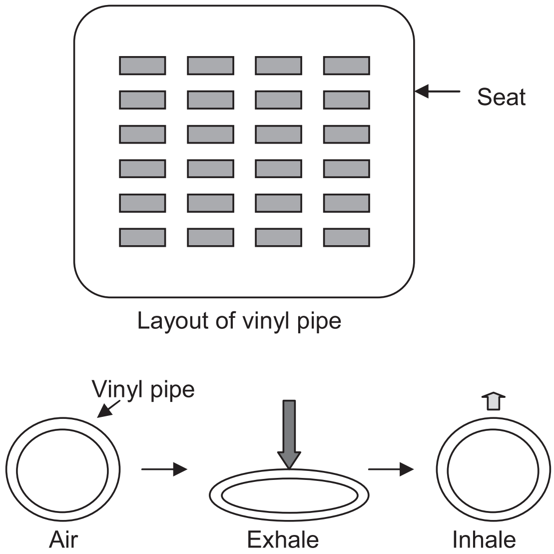


Fig.18 Pumping mechanism to self-breathing

8.2 Experimental procedure and results

In the room condition, the subject who sat down gave one time of top and bottom vibration for 20 seconds and measured seat temperature after 30 minutes. 2-dimensional emission type thermometer was adopted for a temperature measurement.

Fig.19 shows an example of a photography image of a thermometer.

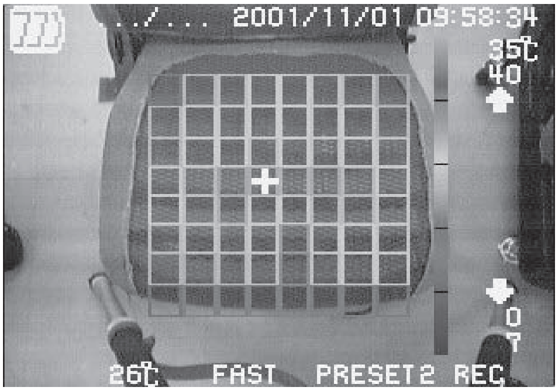


Fig. 19 An example of a photography image of a 2-dimensional emission type thermometer

Fig. 20 shows an example of a measurement result. The number in figure displays the difference of temperature by degree in before and after of experiment. In comparison with a commercial seat, it was confirmed that a rise of temperature is suppressed somewhat [7].

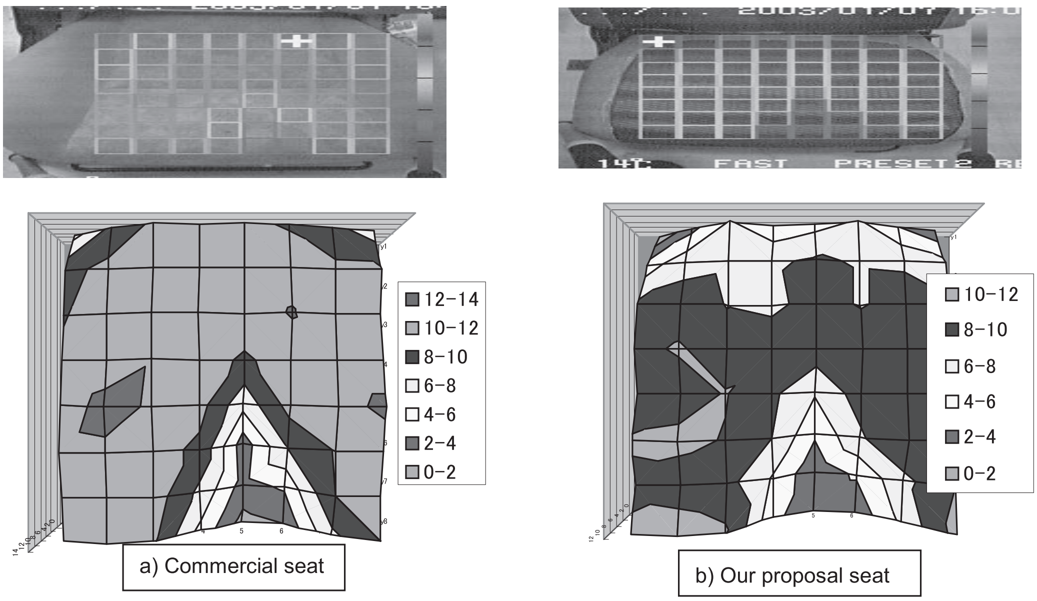


Fig. 20 examples of the measurement results

9. Conclusion

In this study, it was a main purpose to simulate the passenger's neck behavior in an actual vehicle collision at low speed. This experimental result could not provided us with enough data systematically, but some useful information was obtained in order to suppose a cause of the neck damage in the rear-end collision at low speed.

As a result, the occurrence of compressing movement from the cervix to the spinal cord was suggested in the experiment that was conducted with a driver's seat for a general passenger car, and it was suggested by using the computer simulation that the existence of this compression load may make out the shearing deformation concentration on the neck bottom. Consequently, to reduce the whiplash injury in the rear-end collision at low speed, it is necessary to restrain the sharp compressing movement in the neck, and on the other hand, the specific characteristics of the seat, for example, to control the effective temperature is with importance for passenger to maintain appropriate seating posture.

References

1. Yukio Kanayama, Yuzuru Matsuura, "A Study of Passenger's Whiplash Behavior during Rear-endCollision of a Vehicle at Low Speed, 1st.Report; Development of a device simulating an actual vehicle collision and a proposal seat of reducing whiplash input", Congress of Innovative Occupant and Partner Crash Protection in Berlin (2003).
2. Adam Wittek, Koshiro Ono, et. al., "Analysis of Activity of Cervical Muscles in Unexpected Low Speed Rear-End impacts", Japan Society of Automobile Engineering Lecture Paper, No.37-00, pp5-8 (2000)"
3. Tomoyasu Matsushita and Kiyoshi Hirabayashi, "Analysis of Cervical Motion and Neck Injury Mechanisms During Low Speed Rear-end Collisions", Japan Society of Automobile Engineering, Paper, Vol.32, No.3, pp101-106 (2001), in Japanese.
4. Yoichi Watanabe, et al. "Rear Impact Whiplash Neck Injury Reduction Technology", Journal of Japan Society of Automobile Engineers Paper, Vol.53, No.11, pp83-87 (1999), in Japanese.
5. White paper on traffic safety in Japan 2002, pp1 (2003), in Japanese.
6. The fact of traffic accident from automobile insurance data 2001, the report published

by the Marine and Fire Insurance Association of Japan (2003), in Japanese.
7. Yukio Kanayama, Patent number ; 4604244 in Japan.