Study of Chest Injuries by Car Type in Car-Pedestrian Collisions Based on Finite Element Analysis

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Abstract: In the accident analysis of car-pedestrian collisions, a frequency of chest injuries of pedestrian hit by one-box type vehicle (flat front shape vehicle) is higher than that by bonnet-type car. In this study, the factors that can affect injuries to the chest of pedestrian by front shape vehicle were investigated using a finite element analysis. A human finite element model (THUMS) was used, and was collided by a bonnet-type car and a one-box vehicle at 40 km/h. The deformation and the stress of the rib cage were compared for both types of vehicles. In the bonnet-type car collision, the pedestrian was wrapped around the bonnet, and the chest impacted the bonnet top. On the other hand, in the one-box type vehicle, the pedestrian's chest was directly impacted by the front of the vehicle. An impact velocity of the chest against the vehicle was smaller for the bonnet-type car than for the one-box type vehicle. In the bonnet-type car, since the stiffness of the bonnet top where the chest impacted was distributed and the bonnet did not bottom-out against the engine, deformation of the thorax was small and uniform. On the contrary, in the one-box type vehicle, because the chest was hit by the stiff windshield frame, the thorax was deformed locally due to high stress. The result showed that vehicle shape can affect the chest impact velocity, and stiffness distribution of the vehicle structure can affect chest deformation and its mode.

Keywords: Pedestrian protection, Chest injury, Finite element analysis

1 Introduction

According to the analysis of accident data in Japan, recently the number of fatalities in traffic accidents is decreasing every year. However, the prevalence of pedestrian fatalities increases every year, and in 2008 it accounts for 33.4%, which was larger than that of vehicle occupants (33.2%) in Japan. To reduce these pedestrian fatalities and to progress the pedestrian protection, understanding of the pedestrian injury mechanisms in each body region is necessary. According to global accident data in Japan in 2008, for pedestrian fatalities, prevalence of the head, chest and pelvis injuries was 55.8%, 16.7% and 8.4%, respectively. For pedestrian serious injuries, prevalence of the head, chest, pelvis and lower extremities was 16.5%, 4.2%, 9.4% and 36.0%, respectively. There are many researches which deal with the head and lower extremity injuries to pedestrian. According to these researches, test procedures using headform, legform and upper legform impactor to evaluate the injury risks have been developed [1]. Based on these test procedures, several regulations and new car assessment program (NCAP) for pedestrian protection are conducted. Although chest injuries are frequently observed in vehicle-pedestrian collisions, a few researches have conducted to understand the mechanisms of chest injuries of pedestrian.

The pedestrian kinematic behavior in vehicle-pedestrian collision is affected by vehicle shape. For example, the pedestrian shows wrap trajectory in collisions with bonnet-type cars, and shows forward projection in collisions with vans (box-type vehicle) [2]. According to the comparison of injury risks by vehicle type using global and in-depth accident data, the chest injuries occur more frequently for vans than that for cars and sport utility vehicles (SUVs) [3]. Multibody simulations of pedestrian-vehicle collisions using MADYMO were carried out, and have shown that the chest acceleration was higher for the van compared for the car [3]. Shen et al. [4] also conducted mutlibody simulation of flat-front vehicles to pedestrian collisions, and concluded that the injury risk to thorax and abdomen was high for this vehicle type because the chest acceleration and the abdominal force were large in the pedestrian model. To examine the injury potential of pedestrian in detail, finite element (FE) analysis using human model is useful. In this research, FE analyses were carried out for collisions of pedestrian against the one-box vehicle (the van with flat front shape) and the bonnet-type car. Loadings and deformation of the chest of the pedestrian were examined to understand the relation between chest injuries and vehicle shapes.

2 Accident analysis

Using in-depth accident data in Japan, distributions of injured body regions were shown for minor (AIS of 1or 2) and severe (AIS of 3 or more) injuries which were classified by the bonnet-type car and the one-box type vehicle (Figure 1). For severe injuries in collisions of one-box type vehicles, the head and chest are most frequently injured body regions, and the prevalence of head and chest injuries occupy 54% and 35%. In mild injuries, the head (21%), upper extremities (28%) and lower extremities (31%) are major regions of injuries. In bonnet-type car collisions, the prevalence of the head injuries is large in severe injuries (40%), and the prevalence of lower extremity injuries is large in minor injuries (45%). In minor injuries, the head, upper extremities and lower extremities are major regions of injuries. The prevalence of chest injuries (AIS 3+) are smaller (13%) for bonnet-type car compared to that for one-box type vehicle (35%).

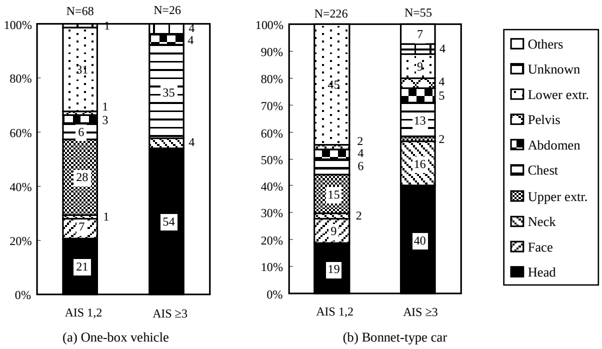

Figure 1 Injury body regions of pedestrian in collisions with one-box type vehicle and bonnet-type car (in-depth accident data, ITARDA report 1999)

3 FE model

The FE models of mini one-box vehicle, bonnet-type car and human model were used (Figure 2). The mini one-box type vehicle was developed from its shape and material properties. The dimension of the front shape of the one-box type vehicle was measured by a measurement instrument device. The shape of each part, such as bumper, front panel and A-pillar was measured and assembled into the vehicle model. The material properties of each part were determined by the result of tensional tests of the specimen. The number of nodes and elements of front part of the one-box type vehicle model were 64,451 and 74,451, respectively.

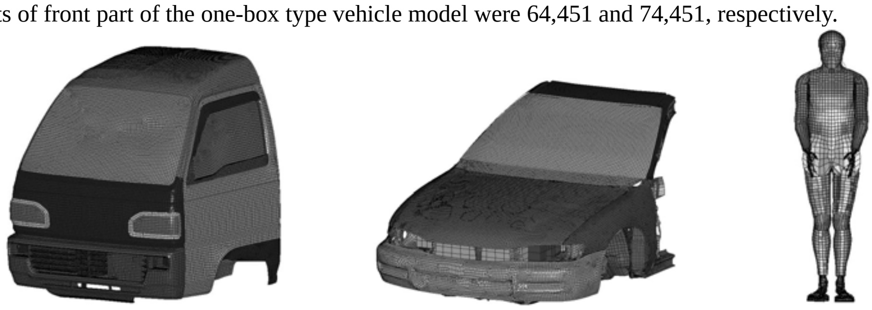

Figure 2 One-box type vehicle, bonnet-type car and pedestrian FE model

In order to validate the FE model of the one-box type vehicle that was made, headform impact tests were carried out. A headform (4.5 kg) was impacted against various location of the one-box type vehicle. An impact velocity was 40 km/h, and impact angle was 0 degree at front panel and windscreen frame, and 50 degrees at windscreen center. The simulation results were compared with those of experiments. The acceleration of the impactor tested for front panel, lower windshield frame and windshield center is shown in Figure 3. The headform acceleration of the FE simulation agrees with that of experiments.

A bonnet type car model used in this study was modified from Accord FE model of NCAC (National Crash Analysis Center). The front part of the model was used from the original FE model. The elements of bumper, bonnet panel, cowl and windshield were subdivided. The number of nodes and elements were 83,024 and 100,048, respectively. The headform impact test simulations were conducted to validate the deformation. As a human FE model, THUMS (Total HUman Model for Safety) pedestrian model (AM50) was used.

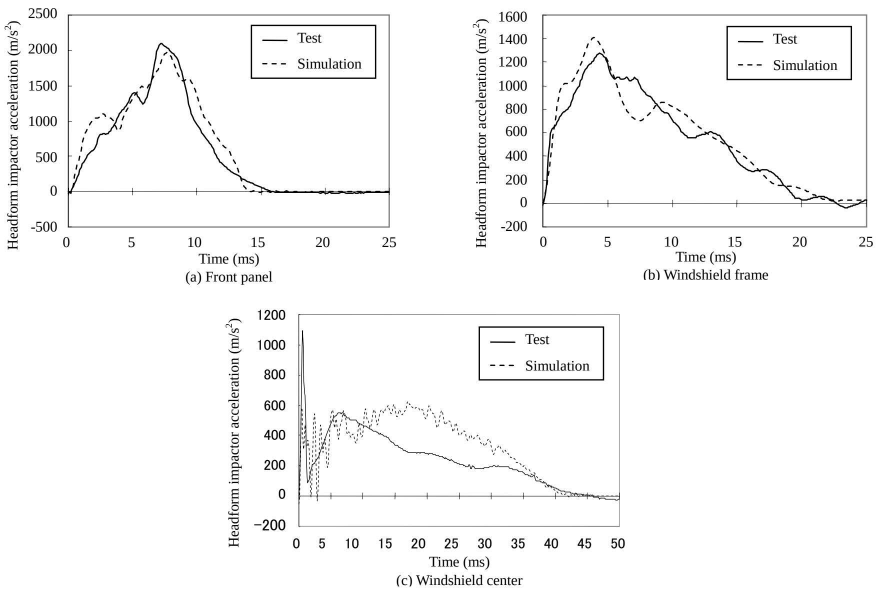

Figure 3 Headform impact tests for one-box type vehicle (front panel)

4 Thorax loading by vehicles with two types of shape

In order to understand the mechanism of the chest injury of the pedestrian, it would be useful to compare the thorax loading by the bonnet type car and the one-box type vehicle. To understand the contributing factors to the chest injuries of the pedestrian, mechanisms of thorax deformation was examined for a bonnet-type car and a one-box type vehicle. From the understanding the injury mechanism in both vehicles, the causes in high frequency of chest injuries in collision with one-box type vehicle could be clarified. In this research, the pedestrian FE model was hit from pedestrian's side at 40 km/h by a bonnet-type car and a one-box type vehicle FE model with its center location.

5 Kinematic behavior of pedestrian

Pedestrian showed different kinematic behavior in collisions with one-box type vehicle and bonnet-type car. Kinematics behaviors of the pedestrian in collision with one-box type vehicle and bonnet-type car are shown in Figure 4 and 5, respectively. In the collision with the one-box type vehicle, lower extremities made contact with a bumper, and the pelvis and the lower thorax contact to a front panel in a short time of duration. The upper thorax and the head were contacted with a windshield after these impacts. The windshield deformed greatly because of its low stiffness, and the upper thorax and the head moved into the windshield, which led to the lateral flexion of the upper body of the pedestrian.

In the collision with the bonnet type car, the tibia made contact with a bumper, and the femur made contact with a hood leading edge. Then, the pedestrian wrapped around the front shape of the car, and the pelvis impacted on the bonnet top. The pedestrain torso rotated around the pelvis, and the thorax made contact directly with the bonnet top. The pedestrian's head made contact with the cowl of the car at 120 ms.

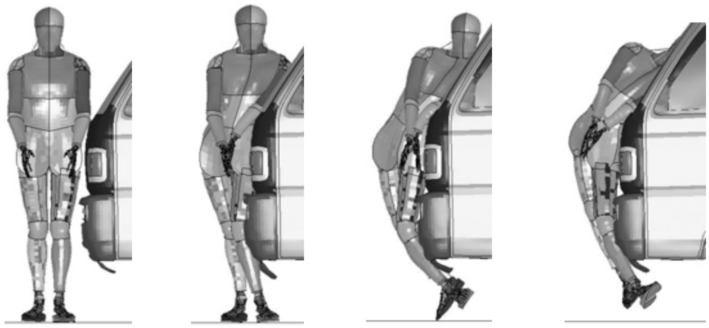

Figure 4 Kinematic behavior of pedestrian in one-box type vehicle impact (time zero is car contact with pedestrian).

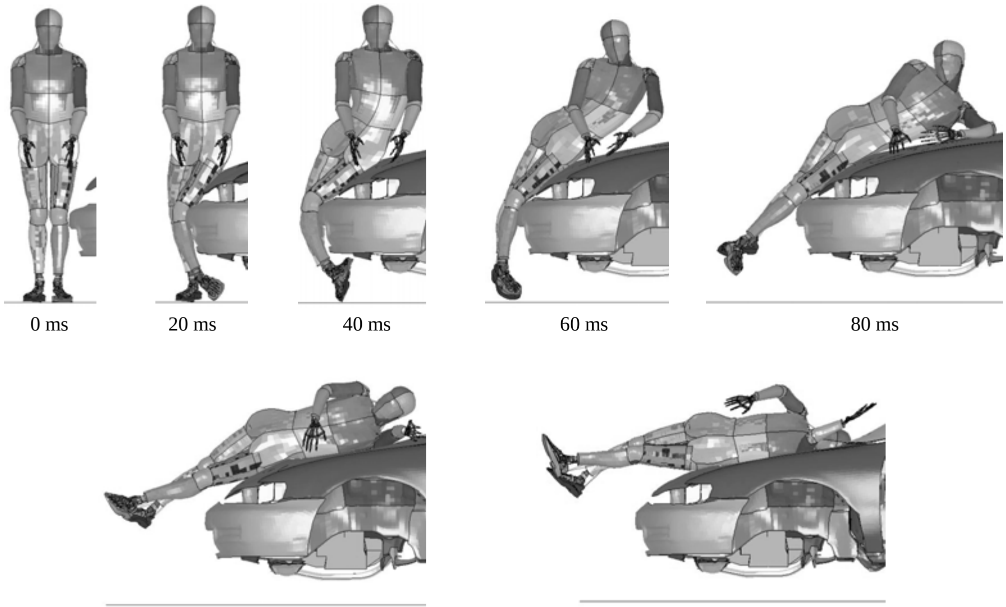

Figure 5 Kinematic behavior of pedestrian in bonnet-type car impact (time zero is car contact with pedestrian).

6 Impact speed of the chest onto the vehicle

An impact velocity of the chest against the vehicle could affect loading and the injury severity to the chest. Therefore, a resultant velocity of the chest with respect to the car was compared for the one-box vehicle and the bonnet-type car (Figure 6). In the collision with the one-box type vehicle, the chest was impacted directly with the front panel of the vehicle in vehicle's traveling direction. The chest velocity relative to the vehicle decrease consistently until 60 ms. Since the time interval between lower extremities contact and chest impact was short, the pedestrian was not accelerated enough in vehicle's traveling direction and the velocity of the chest relative to the vehicle was still high (9.6 m/s) compared to an initial collision velocity (11.1 m/s). In the bonnet type car collision, the upper body of the pedestrian rotated around the car, which could lead to a high velocity due to vertical velocity component. However, since the pedestrian accelerated toward car direction gradually after the collision, the velocity relative to the car was already low (7.8 m/s) when the chest made contact with the bonnet-top. Accordingly, the relative velocity at the time at the contact of the chest with the vehicle was lower for the bonnet-type car than that for the one-box type vehicle due to the difference of kinematic behavior of pedestrians.

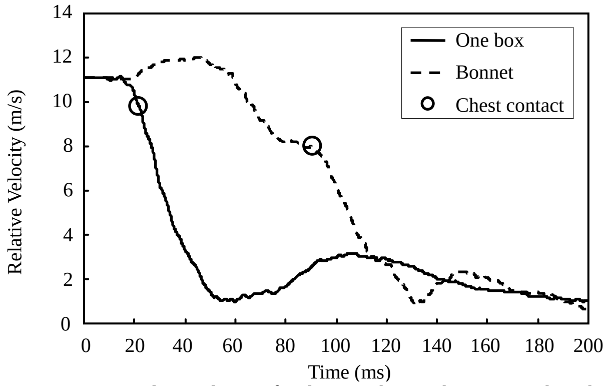

Figure 6 Resultant velocity of pedestrian chest with respect to the vehicle.

7 Thorax deformation

Figure 7 shows the deformation and the stress distributions of pedestrian rib cage in the one-box vehicle collision. The stiff windshield frame pushed the lower rib cage of the pedestrian. The upper thorax moved into the windshield because of the low stiffness of the windshield. As a result, a shear loading was applied to the thorax due to stiffness difference between the stiff windshield frame and the less-stiff windshield. The local deformation was observed in the rib cage by contact with the windshield frame. As a result, a high stress was observed in the lower ribs, whereas the stresses in the ribs which made contact with the windshield were small.

In the case of a bonnet-type car (see Figure 8), because the stiffness of the bonnet top is distributed over the whole bonnet top, the bonnet top deformed uniformly and absorbed energy efficiently in the impact with the pedestrian chest. Although the bonnet panel deflected, the clearance of the bonnet top from the engine was large enough for the bonnet panel to bottom out the engine, which prevented large thorax deformation. As the force was transmitted from shoulder joint during impact, relatively high stresses were observed around the clavicle and first rib.

Figure 7 Pedestrian skeleton deformation and von Mieses stress distribution in the collision with one-box type vehicle

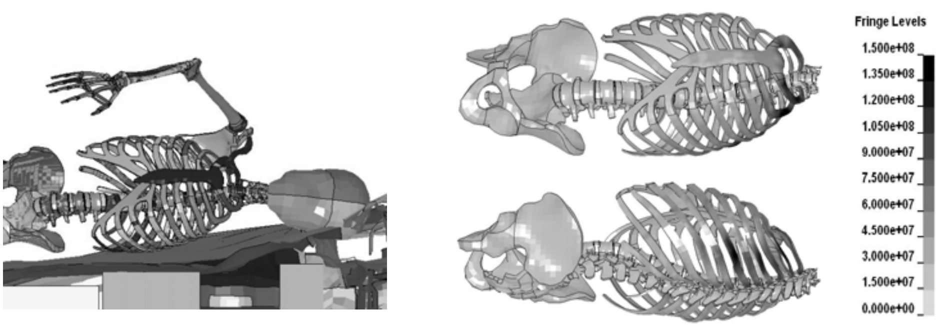

Figure 8 Pedestrian skeleton deformation and von Mieses stress distribution in the collision with bonnet-type car

8 Discussion

Accident analysis have shown that the injury risk to pedestrian is high in the collision of one-box type vehicle. The severely injured body regions are the chest and head for one-box type vehicle collisions, whereas they are the head and lower extremities for bonnet-type car collisions. To understand the mechanism of chest injuries in one-box type vehicle, FE analysis using human pedestrian model was carried out. In one-box vehicle, the pedestrian was projected forward, and the chest was impacted directly from the front panel. Then, the chest impact velocity against the one-box type vehicle was high. For the bonnet-type car, because the pedestrian was wrapped around the car front shape, the chest impact velocity relative to the car was reduced. Accordingly, the difference in kinematic behavior of pedestrian in a collision of vehicles can lead to the different impact velocity and loadings of the chest. Accordingly, the front shape of the one-box type vehicle could be one of causes of high frequency of chest injuries of pedestrian.

From FE analysis, in a collision of one-box type of vehicle, the local deformation of the pedestrian thorax occurred due to stiff windshield frame. On the other hand, in a collision of bonnet-type car, the thorax deflected uniformly with small deformation due to distributed stiffness of the bonnet-type car. Therefore, the deformation mode of thorax due to local stiffness of the one-box type vehicle could also be the cause of high frequency of chest injuries. Consequently, it is probable that both the kinematic behavior of the pedestrian as well as local stiffness of the vehicle structure lead to high frequency of chest injuries of one-box type vehicle in real-world collisions.

9 Conclusions

In this study, finite element analyses of vehicle-pedestrian collisions for vehicles with two different shapes (one-box type vehicle and bonnet-type car) were carried out, and contributing factors to chest injuries were examined. According to the accident data, a frequency of the chest injury is high for the one-box type vehicle whereas it is low for the bonnet-type car. In the FE analysis, the pedestrian was projected forward by the one-box type vehicle, and the chest made contact with the front panel at a high velocity. The lower rib cage of the pedestrian deformed locally with the stiff windshield frame of the one-box vehicle. For the bonnet-type car, the pedestrian wrapped around the car, and the chest made contact with the bonnet-top with low velocity. The bonnet panel deformed uniformly and the deformation of the pedestrian’s thorax was small. It is probable that the vehicle shape could affect the chest impact velocity and the vehicle structure or stiffness distribution could affect the deformation of the thorax, and one-box vehicle has a high injury potential to pedestrian in collisions because of its shape and structures.

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