RESEARCH OF PEDESTRIAN INJURY REDUCTION MECHANISM BETWEEN THE BEGINNING OF THE COLLISION AND FALL OF THE GROUND

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ABSTRACT

Recently, safety standards for pedestrian protection in third party evaluation typified by NCAP have been increased, and safety performance of vehicles is improving. Among them, the safety performance of the bonnet hood has been particularly enhanced in terms of injury index represented by HIC from the viewpoint of head protection. However, according to the accident statistics, pedestrian fatalities have remained high, and the causes of death include not only the vehicle injury but also the ground injury. Therefore, it is necessary that pedestrian protection technology includes not only vehicle but also ground. In order to reduce the number of pedestrian fatalities, this research focused on the control of the pedestrian's behavior after accidents and studied methods that can reduce head injuries caused by various factors.

In many pedestrian accidents, the speed difference between the vehicle and the pedestrian is large. The pedestrian is accelerated to the speed of the vehicle due to force input from the vehicle. Therefore, if pedestrians can be gently accelerated, the action is expected to be effective in reducing various injuries. For this purpose, it is important to restrain the pelvis close to the center of gravity at the beginning of a collision. As for the ground, by controlling behavior so that a pedestrian can fall from their leg to the ground, head injury can be greatly reduced. For this purpose, it is important to reduce local input to the legs and suppress the swinging up of the legs. In this research, the effect of early pedestrian pelvis restraint was verified using a pedestrian dummy (POLAR) and modified vehicle model. Head injury was evaluated by using Convolution of Impulse Response for Brain Injury Criterion (CIBIC). For verification, a sedan type vehicle with a small initial input to the pedestrian's pelvis was used, and the collision speed was limited to 40 km/h. Then, based on the vehicle model, which can change the input part and the load characteristics, the relationship between the behavior of the pedestrian and the injury value was studied.

In this research, it was confirmed that the angular velocity of the upper body around the center of gravity is reduced by the early input to the pedestrian pelvis, and it is effective for various injury values of the head. It was also confirmed that the swinging up of the leg can be suppressed by controlling the input to the pedestrian leg.

Although collision speed and physique are limited in this research, it is necessary to consider the influence of the difference in physique and speed. Furthermore, it is important to integrate with external sensing technology in order to deploy the pelvis restraint device in front of the vehicle before a collision.

In this research, it was confirmed that a pedestrian behavior control device may be effective for reduction of generalized injury by vehicle crush and secondary damage by the ground as one solution for further reduction of the number of pedestrian fatalities.

INTRODUCTION

Traffic accident fatalities in Japan are trending downward, going from 6,415 fatalities in 2006 to 3,694 in 2017[1]. However, Pedestrian fatalities accounted for about 36% of overall fatalities and traffic accident, and the ratio is the highest among the fatality group. In terms of pedestrian safety performance, evaluation using a subsystem impactor is performed, and head injury is evaluated by HIC. Accidents in the real world include brain damage due to the influence of head rotation at the time of a collision and injuries on the ground. As current sub-system impactors are incapable of evaluating injury caused by head rotation and impact with the ground, a method is needed to evaluate the whole body behavior of the pedestrian throughout the series of events in a pedestrian accident. In many pedestrian accidents, the speed difference between the vehicle and the pedestrian is large. The Pedestrian is accelerated to the speed of the vehicle due to force input from the vehicle, and the upper body rotates toward the vehicle. The pedestrian's head rotates along with the behavior of the upper body, hitting the vehicle. Next, the pedestrian is thrown to the ground by the speed difference with the vehicle and sustains injury. The head injury received on the ground depends on the falling behavior, and allowing the legs to land on the ground could reduce the risk of head injury. (Figure 1) With a focus on the fact that these injuries occur at each step along the series of behavior in pedestrian accidents, in this study, the effect of controlling pedestrian behavior from the point of vehicle impact until ground contact was verified.

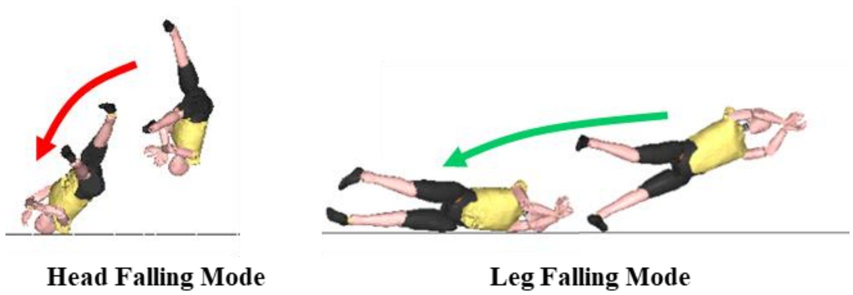

Figure 1. Falling mode from the vehicle

METHODS

Verification of effects from early pelvis restraint

In this study, pedestrian FE model was used POLAR [2]. This model simulates POLAR which was developed as a dummy for pedestrian injury measurement, and enables the verification by actual vehicle test in the course of study. As pedestrian behavior is thought to depend on how the center of gravity is restrained, the vehicle used for verification was a sedan model, which exerts little force on the pelvis close to center of gravity. To verify the effect of early pelvis restraint, a pelvis restraining surface was added to a standard sedan model vehicle. The restraining surface and vehicle were connected by a spring element with load-displacement properties. A single input model to the legs was also prepared for comparative verification, applying the same load-displacement properties as were applied to the pelvis. (Figure 2) (Table 1) The added spring element was determined by the contact load and vehicle side displacement when the pedestrian model was struck. Vehicle models with different restraint characteristics were crashed into the pedestrian model at 40 km/h.

Evaluation criteria

As the pedestrian model response, longitudinal velocity at the pelvis and the angular velocity around the pedestrian's center of gravity were confirmed. Brain injury of Pre-Impact phase was evaluated using Convolution of Impulse Response for Brain Injury Criterion (CIBIC) from the research of Takahashi et al. [3] The trajectory of the head to the vehicle was measured to verify the behavior of the pedestrian dummy model.

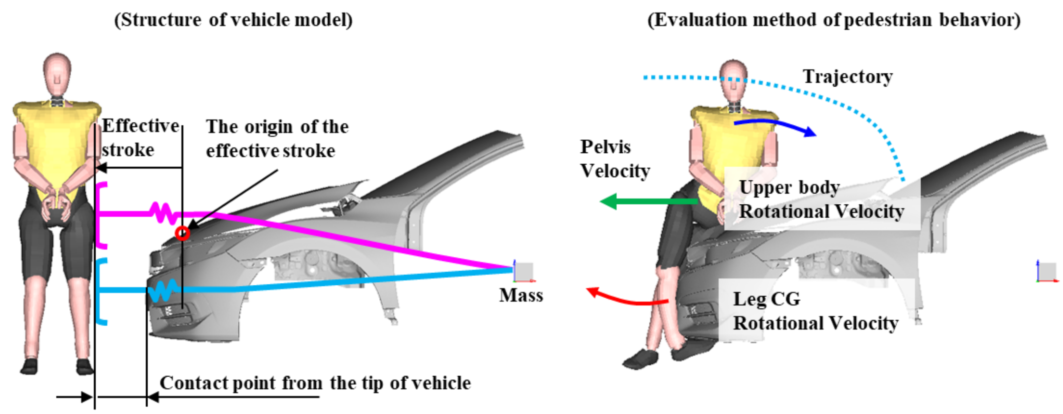

Figure 2. Structure of vehicle model and evaluation method of pedestrian behavior

Table 1.
Restraint characteristics

	Contact point from vehicle (mm)	Spring characteristic for Pelvis			Spring characteristic for Leg		
		Force (N)	Effective Stroke (mm)	Energy (J)	Force (N)	Effective Stroke (mm)	Energy (J)
Original	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Case (a)	260	4.0	420	840	N/A	N/A	N/A
Case (b)	230	4.0	390	840	N/A	N/A	N/A
Case (c)	150	4.0	310	620	N/A	N/A	N/A
Case (d)	100	4.0	260	520	N/A	N/A	N/A
Case (e)	50	4.0	210	420	N/A	N/A	N/A
Case (f)	0	4.0	160	320	N/A	N/A	N/A
Case (g)	-50	4.0	110	220	N/A	N/A	N/A
Case (h)	260	N/A	N/A	N/A	4.0	420	840
Case (I)	230	N/A	N/A	N/A	4.0	390	840
Case (j)	150	N/A	N/A	N/A	4.0	310	620
Case (k)	100	N/A	N/A	N/A	4.0	260	520
Case (l)	50	N/A	N/A	N/A	4.0	210	420

RESULTS

Comparisons of movement

The pelvis longitudinal velocity, angular velocities of the upper body and legs around the center of gravity, cranial velocity perpendicular to the vehicle, and head trajectory, all taken when the restraint characteristic vehicle models and the pedestrian dummy models collided, are given in Figures 3-7, respectively. As the collision progresses, input force from the vehicle body clearly accelerates the pedestrian, with the upper body being wrapped onto the vehicle by a rotational motion and the lower body swinging up. In Figure 3 and Figure 7, the pelvis velocity of original case occurs slowly due to no direct input to the center of gravity and it is confirmed to be large head displacement. In the pelvis restraint model, change in the upper body angular velocity and head collision velocity is dependent on the restraint characteristics. In Case (a), the pelvis slowly accelerates from the start, and the center of gravity is restrained properly. Meanwhile, while the upper body angular velocity for the leg restraint model exhibits the same tendencies as with the pelvis restraint model, the leg restraint model showed no change in head collision velocity, and head trajectory was equal. In terms of head behavior, Case (a) in the pelvis restraint model collided most forward. In terms of leg swing-up, while both the pelvis restraint model and leg restraint model reduced the initial generated angular velocity, neither were very effective overall.

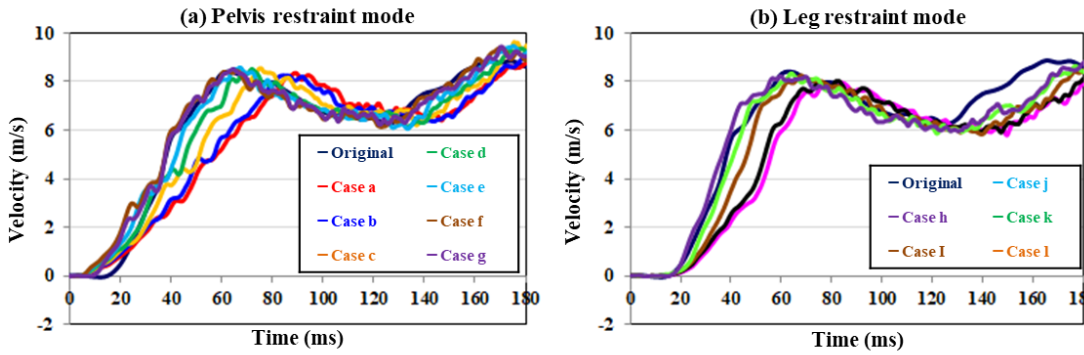

Figure 3. Time history of Pelvis Longitudinal Velocity

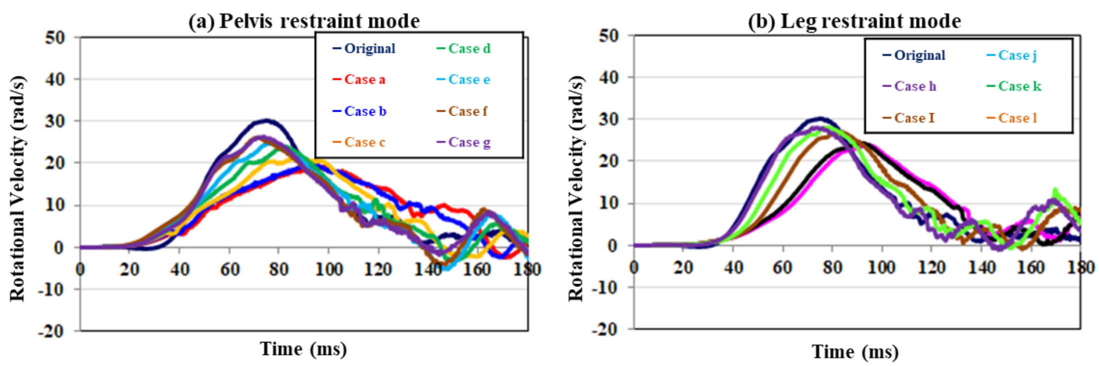

Figure 4. Time history of Upper Body Rotational Velocity

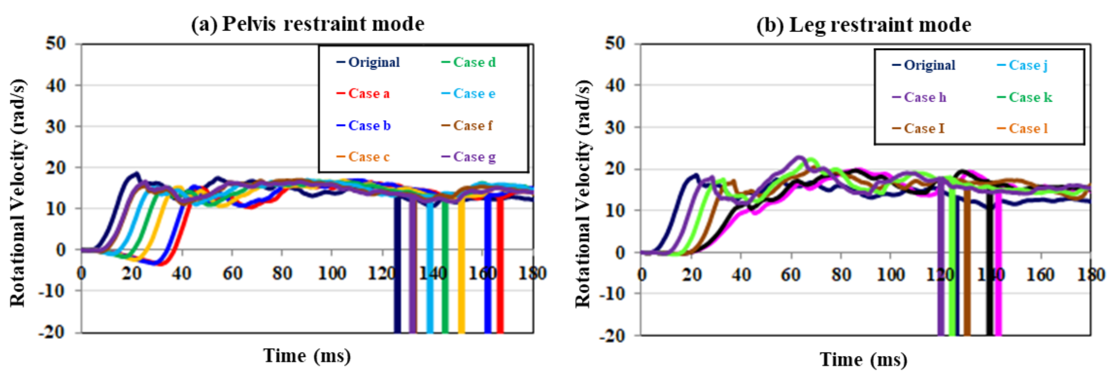

Figure 5. Time history of Leg CG Rotational Velocity

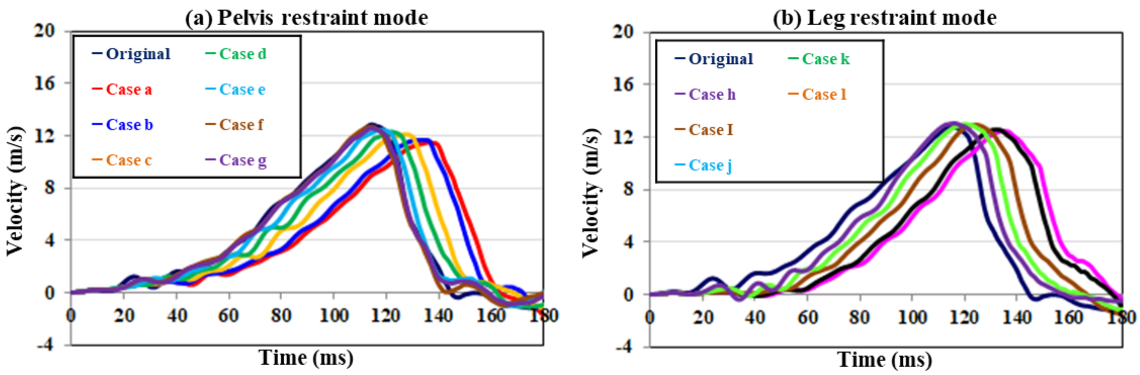

Figure 6. Time history of Pelvis Longitudinal Velocity

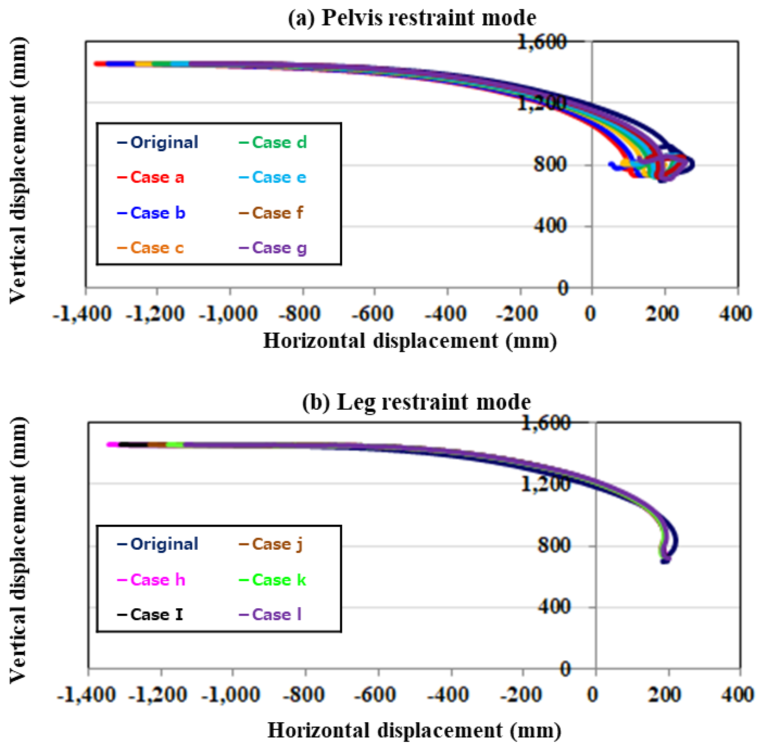

Figure 7. Trajectories

Comparison of injury levels

In this study, brain injury was evaluated in the time region before head collision. Based on the original case, CIBIC of each parameter study case is represented by ratio. (Figure 8) Case (a) of the pelvic restraint model reduced CIBIC during rotation of upper body, and it was found that it is effective to restrain the pelvis close to the center of gravity of the human body to reduce brain injury.

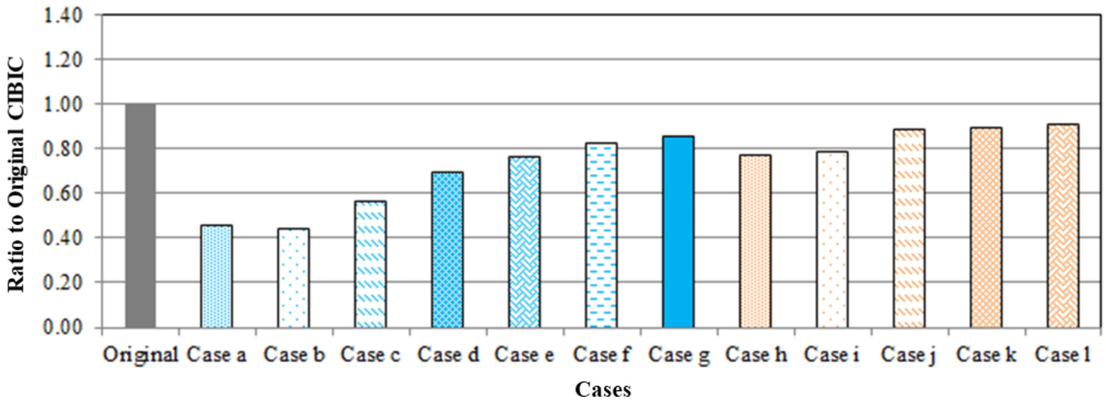

Figure 8. Injury value ratio to original during of upper body rotation

DISCUSSION

Mechanisms for reducing injury

Internal force of the pedestrian dummy was analyzed to understand the brain injury reduction mechanism by the pelvis early restraint. (Figure 9)

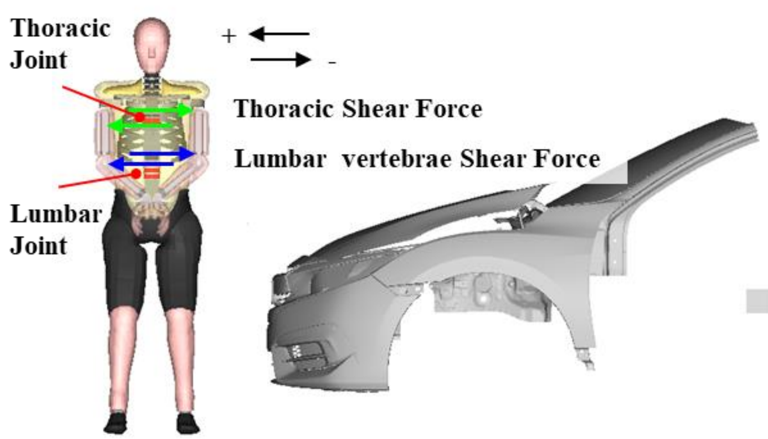

Figure 9. Dummy internal force analysis

The intracranial strain waveform and pedestrian dummy behavior generated by head rotation in the Original case is shown in Figure 10 and Figure11. As shown Figures 10 to 11, CIBIC before head collision is generated 120 ms prior to collision between the vehicle and head. Yanaoka mentioned that pedestrian CIBIC showed multiple peaks from in pre-impact to impact phase [4]. The result of this study showed the same tendency. Thus, internal force was analyzed within the range of 0-120 ms.

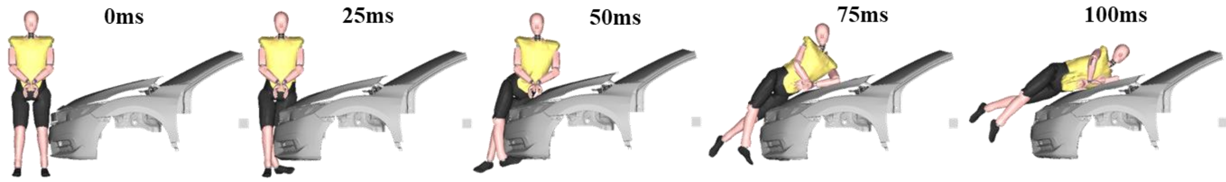

Figure 10. Pedestrian dummy behavior in original case

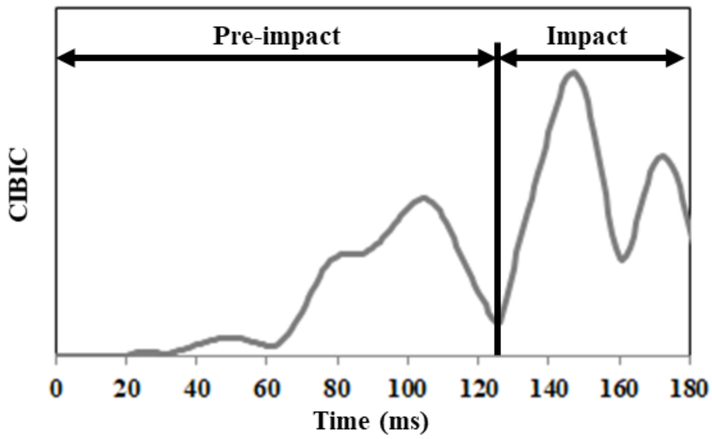

Figure 11. CIBIC waveform of the original case

In the pelvis restraint model and leg restraint model, shear force generated in the thoracic and lumbar vertebrae were measured to verify the impact to head rotational behavior. (Figure 12, Figure 13) For Case (a), the shear force of thoracic was the closest to 0 and the shear force of lumbar vertebrae was the smallest. This result shows that the dummy rotation behavior has changed depending on the restraint characteristics.

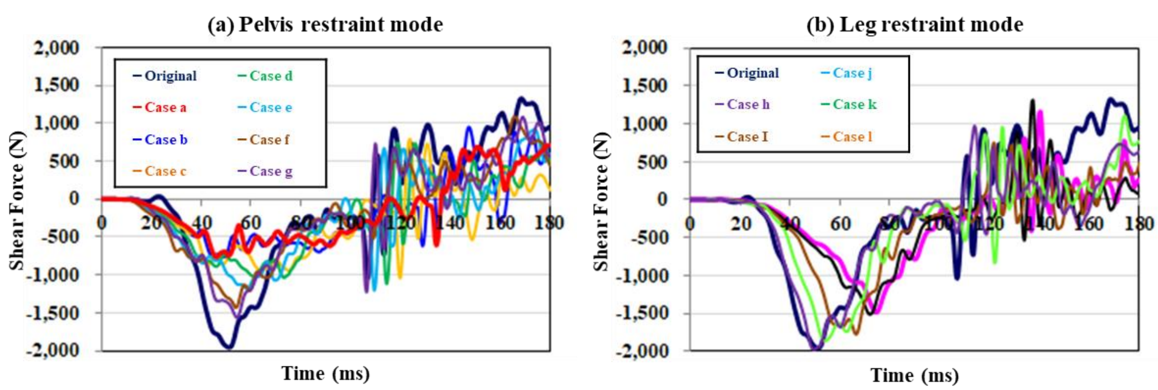

Figure 12. Time history of Thoracic shear force

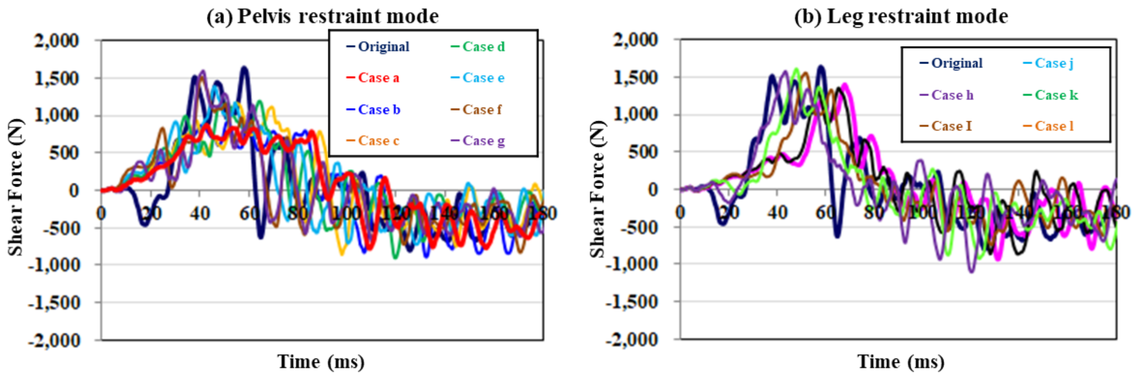

Figure 13. Time history of lumbar vertebrae shear force

The relation between the CIBIC levels of each restraint characteristic with the Original level being 1 and the thoracic shear force peak values up to 120 ms is shown in Figure 14. In Figure 14, there is a clear correlation between CIBIC levels and thoracic shear force. As head rotation is generated by upper body rotation and inertia of the head, reduction the upper body rotation through this interaction within the pedestrian dummy reduced the brain injury. Next, the relation between thoracic and lumbar vertebrae shear force is illustrated in Figure 15. In Figure 15, there is a clear correlation between thoracic and lumbar vertebrae shear force, softly restraining the dummy with its center of gravity have efficacy for brain injury reduction.

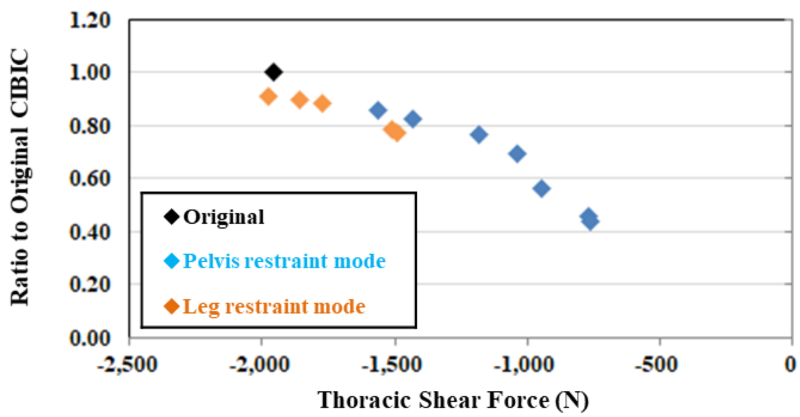

Figure 14. Relationship between Raito to original CIBIC and Thoracic Shear Force

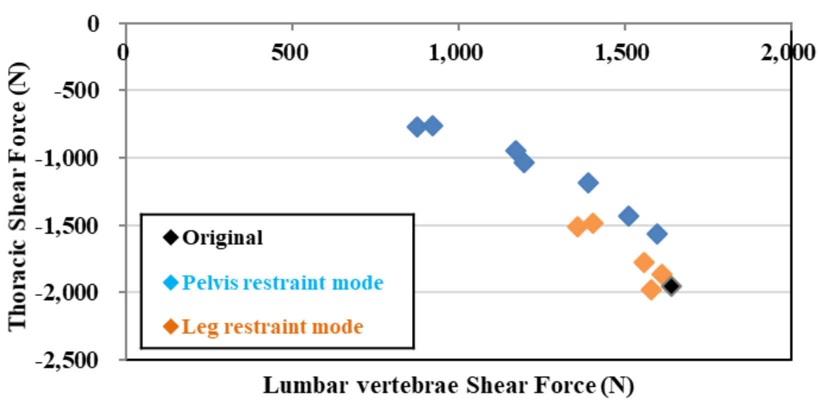

Figure 15. Relationship between Thoracic Shear Force and Lumbar Vertebrae Shear Force

LIMITATION

In this study, pedestrian dummy models were used for verification. The cervical characteristics affecting head rotation need to be compared with human body characteristics. This study focused on an AM50% model at a collision velocity of 40 km/h, leaving the impacts at different physiques and velocities as outstanding issues for future studies to consider. More study is also needed on how to reduce CIBIC when head and vehicle collide. This will require tests using actual pedestrian dummy to confirm the mechanism for reducing injury criteria value.

CONCLUSIONS

In this study, the effect of reducing injury by controlling the behavior of pedestrians between the beginning of collision and the fall of the ground was verified. In order to control the behavior of pedestrian, it is important to softly restraining of the center of gravity close to the pelvis, and as a result, it was confirmed that it is effective in reducing the brain injury due to head rotation. Although it was effective to reduce the leg angular velocity with respect to the ground influence and suppress the swinging up of the leg, it was confirmed that the effect was small with only the pelvis restraint alone.

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