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Passenger Injury Analysis Considering Vehicle Crash after AEB Activation

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ABSTRACT – Owing to an increasing autonomous emergency braking (AEB) adoption, emergency braking before crash occurs more often than in the case of conventional vehicles. Due to the sudden deceleration in AEB activation, passengers move forward before the crash. To explore how this forward movement affects passenger injury, sled tests are performed with an inclined dummy representing forward displacement. The test shows that a shorter distance between the airbag and passenger results in bigger neck injuries induced by airbag deployment force. A countermeasure is suggested to prevent neck injury in emergency braking situation by reducing deployment force and protrusion.

INTRODUCTION

Several countries have started to adopt active safety estimation in New Car Assessment Program (NCAP). IIHS is evaluating autonomous emergency braking test, and EURO NCAP is also evaluating AEB city/inter-urban. Consequently, AEB adoption rate is increasing rapidly. AEB is very effective in reducing accident rates; however, it cannot bring the accident rate to zero. Even if AEB is activated properly, a vehicle cannot avoid an accident when it moves at high velocity or when another vehicle interferes abruptly. When a vehicle is decelerated suddenly by the driver or the vehicle itself, the passenger tends to fail to notice the braking situation. Due to ignorance, the passenger occupant moves forward without any preparation for sudden braking and becomes closer to passenger-side air bag (PAB). In an AEB-adopted vehicle, emergency braking before the crash occurs more often than it would in a conventional vehicle. However, NCAP and a regulation crash test cannot reflect this sudden forward moving situation. Anthropometric test devices (ATDs) sit in a standard position without considering forward displacement after emergency braking. The restraint system, such as airbag, is designed to satisfy NCAP and regulation requirement. It means that there is no consideration of emergency braking in the current restraint system development. Because of the high recent AEB-adoption rate, consideration of emergency braking is necessary in restraint system development. Particularly, airbag needs more consideration because it deploys high and intensive power. There have been a few studies of driver occupant injury considering vehicle crash after AEB activation (Fumihito K. et al, Garam J. et al.). However, no research focused on the passenger side. The present study addresses passenger occupant injuries with forward movement induced by emergency braking and suggests a PAB countermeasure.

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METHODS

The moving distance of passenger occupant head is based on the research, which measured the forward displacement of the occupant in AEB-activated condition (Garam J. et al.). Hybrid-III dummies were used, and the test scenario was based on the Euro NCAP Car to Car Rear stationary test. Maximum head displacement after emergency braking was 162 mm in hybrid-III female 5%ile dummy with the seatbelt fastened. In this study, the occupant injury is evaluated in emergency braking sitting and normal sitting using a sled facility. The used crash mode is the frontal full width barrier crash at 56-kph speed. To reflect the emergency braking situation, a measured forward displacement of 162 mm is adopted (Fig. 1). The dummy's upper body is reclined to make the head move to the front before the sled test. Even if the upper body moves, the hip point is fixed. The dummy's head frontal displacement makes the distance between the head and PAB much closer than standard sitting before test.

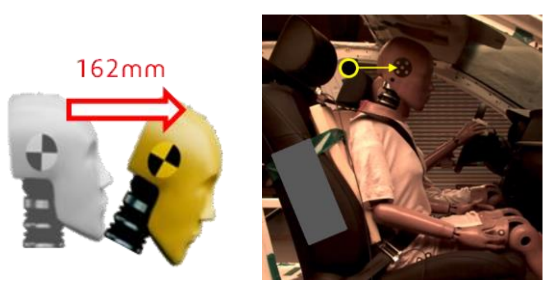

Figure 1 Forward displacement sitting

In the normal position, the dummy sits according to the US NCAP procedure for a hybrid-III female

5%ile dummy. In the present study, passenger occupant injuries are analyzed and compared between normal and forward sitting condition, describing the AEB-activated situation. Moreover, a countermeasure airbag is adopted and evaluated.

RESULTS

Test specifications are summarized in Table 1, and test results are presented in Table 2. The described neck injury values are maximal values. Extensions and flexions are y-axis moments, whereas tensions and compressions are z-axis forces. Injury values before airbag contact and after rebound are not considered.

Table 1 Test specifications

Test No.	Sitting	Airbag
#1	NCAP	Normal
#2	Forward	Normal
#3	Forward	New concept

Table 2 Test results

Injury	Test #1	Test #2	Test #3
HIC	362	262	159
Neck ten.	840 N	1212 N	697 N
Neck comp.	341 N	588 N	484 N
Neck ext.	17 Nm	26 Nm	20 Nm
Neck flex.	19 Nm	35 Nm	19 Nm
Chest def.	10 mm	12 mm	10 mm

In forward displacement sitting (Test #2), the dummy is loaded onto the airbag earlier than in standard sitting (Test #1). The short distance between the head and the airbag causes an earlier contact. Contact time between the head and airbag cushion is 40 ms in Test #1 and 34 ms in Test #2 (Fig. 2).

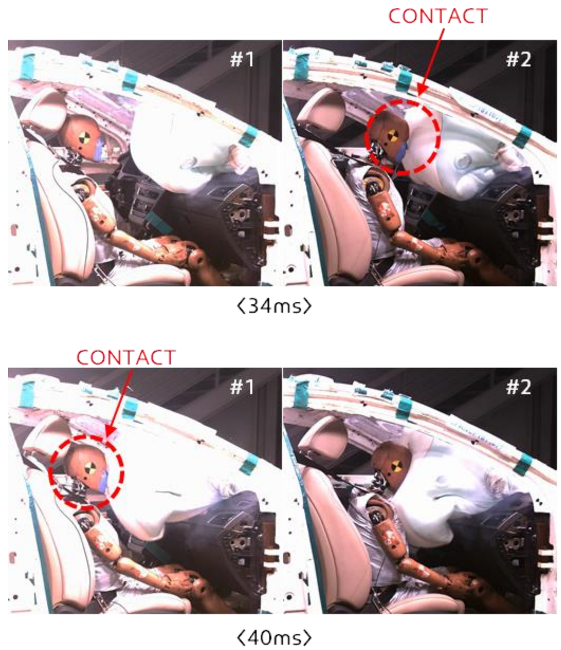

Figure 2 PAB Contact comparison (Left: Test #1, Right: Test #2)

When the forward moved dummy comes into contact with PAB, the cushion is not fully deployed. Therefore, the airbag deployment force affects dummy's head. The deployment force pushes dummy's head and increases neck moments and forces. While the cushion is being deployed, it makes the head move upward and downward. Fig. 2 shows in detail how the forward displacement sitting results in a neck injury. Early cushion contact causes more neck injury (Test #2). Neck injury peak values increased by 53% for extension, 84% for flexion, and 44% for neck tension in comparison to standard sitting (Test #1). Even if the injury values of Test #2 are lower than regulation criteria, it can deteriorate NCAP scores (IARV: Neck ten. 2900N and Neck moments 57Nm in UN R137 for Hybrid-III 5%ile female). When the cushion comes into contact first, deployment force results in more neck flexion and tension. After the contact, neck extension and compression increases within 80−95 ms, indicating that emergency braking before a crash could increase the neck injury of the passenger occupant. The new airbag concept is evaluated to mitigate passenger occupant's neck injury in an emergency braking crash situation. To reduce the deployment force and protrusion of the airbag cushion, the airbag cushion is separated by two extra-inner panels. The panels limit the interaction between the head and the airbag cushion during the early deploying stage. A variable-length tether is applied to limit the protrusion of the airbag cushion during the early deployment stage. After it is fully deployed, the tether becomes longer by cushion inner pressure. Using the new concept, early interaction between the head and airbag cushion is decreased (Test #3). The neck moment and force is improved during 50−65 ms than Test #2. The neck extension moment during 80−95 ms decreases. Neck injuries of Test #3 are similar to those from Test #1. Head injury (HIC) is less in Test #2 and #3 (with forward displacement) compared to Test #1 (with standard position). The closer distance between the airbag and head results in less acceleration of the head. Therefore, it is obvious that emergency braking does not make the head injury worse.

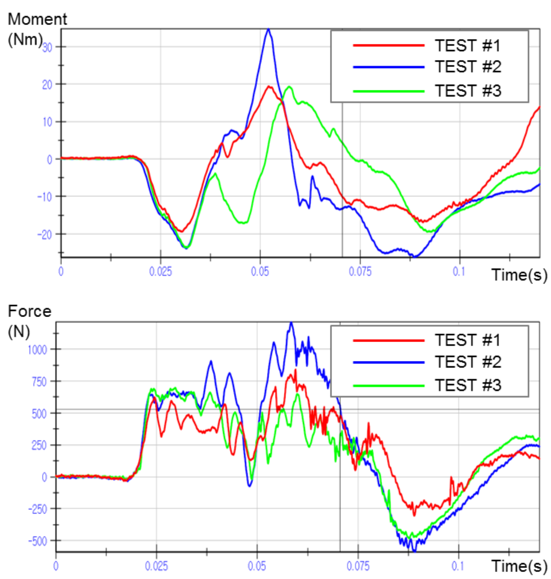

Figure 3 Neck injury
(Upper: Y-axis moment, Lower: Z-axis force)

DISCUSSION

Considering occupant size, tension, and posture, the extent of forward displacement by emergency braking can be changed. Moreover, the extent of displacement is not based on the human occupant but hybrid-III herein. Nevertheless, the forward displacement could certainly deteriorate occupant injury in a crash situation. Thus, the airbag deployment force on the occupant should be diminished in an emergency braking situation. The proposed airbag concept would therefore be effective for the passenger seat.

Scenario-based evaluation could be adopted in the future when it comes to active safety features, such as AEB and active emergency steering. The countermeasure must consider the occupant motion that occurs before crash.

This study analyzes only the frontal full width barrier crash at the speed of 56 kph. Passenger injuries and countermeasures need to be evaluated under more various crash conditions and postures.

After this research, injury patterns induced by emergency braking will be evaluated for other crash modes and vehicle types.

Furthermore, the new test method will be considered for describing forward displacement. Dummies are inclined statically before the test to represent forward displacement by braking. However, forward displacement is dynamic in real situations; thus, the dynamic method representing forward displacement would lead to more realistic results.

CONCLUSION

To simulate a crash after emergency braking, a passenger dummy sat inclined 162 mm forward in a frontal full width barrier crash sled test at the speed of 56 kph. A smaller distance between the airbag and passenger head results in a higher neck moment (y-axis) and force (Z-axis) owing to interaction with the deploying airbag cushion. The countermeasure, which diminishes deployment force and protrusion, can mitigate neck injuries.

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