THE AEB SYSTEM WITH ACTIVE AND PASSIVE SAFETY INTEGRATION FOR REDUCING OCCUPANTS' INJURIES IN HIGH-VELOCITY REGION

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ABSTRACT

AEB(Autonomous Emergency Braking) is a representative safety system that assists a driver to avoid forward collision or mitigate crash velocity resulting in reduction of occupant's injury risk using ADAS sensor. This paper focuses on establishing appropriate PSB activation time in order to minimize occupant forward movement and head & neck injuries in the event of collision when it is unavoidable in the aspect of active and passive safety system integration. And also, it is the other goal that decreases the collision velocity by applying more efficient pre-braking profile. For this, AEB test is performed with H-3 5% & 50% human dummy seated in the passenger side. The test vehicle is equipped with Lidar and camera sensor fusion AEB system, PSB(Pre-Safety seatBelt) and a premium ESC module. From this study, the last time to activate PSB considering occupant's injury and the improved pre-brake profile beneficial to collision velocity reduction and occupant's behavior were verified.

INTRODUCTION

AEB(Autonomous Emergency Braking) is a active safety system that can make a vehicle to avoid collision or mitigate the damage by urgently reducing velocity with the informations obtained using ADAS(Advanced Driver Assist System) sensors such as camera or radar. Camera and radar fusion as shown in ***Figure1*** is typically applied to AEB system due to the system's reliablity in recognition performance and it is expected that single sensor is increaingly adopted to the system for general use.

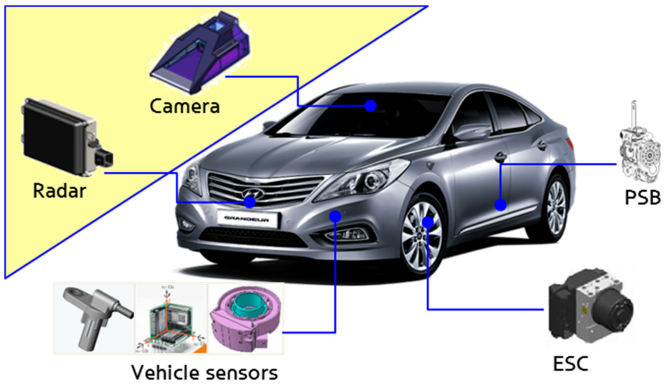


Figure1. Typical AEB system configuration.

From the Thatcham's research report[1] in ***Figure2*** , if the system is applied to the market satisfying the fitmet rate Euro NCAP suggets, it is predicted that the fatalities will be decreased by the 50% of current number. Due to this benefit of the system, Euro NCAP is planning to add AEB-VRU(AEB- Vulnerable Road Users) test to current assesment program with AEB-City/Urban in 2016 and IIHS already evaluate the system for TSP+ requirement in their test protocol.NHTSA is preparing for CIB/DBS tests. AEB system become a most important active safety sytem such as airbag became a essential passive one now after it was firstly adopted and then have made a great contribution to reducing fatalities.

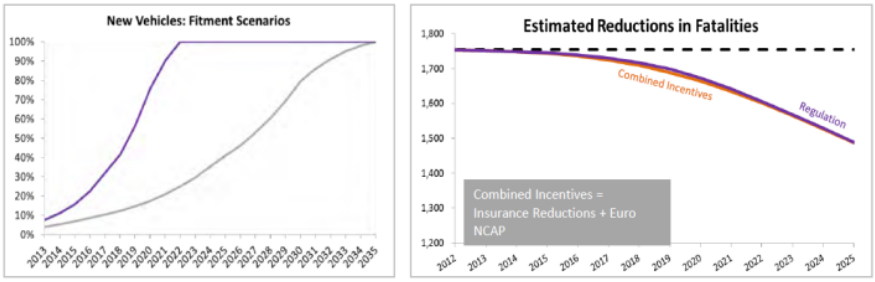


Figure2. Expected reduction of fatalities with the fitment of Euro NCAP AEB.

Now, Euro NCAP AEB test aims that collision is avoided under the relative velocity of 50kph, and IIHS performs their AEB test by 40kph.The AEB system in current test condition is more efficient in reducing occupans' neck injuries in target vehicle by crash avoidance or mitigation in low speed than the one in host vehicle. But it is more important to maximize it's efficiency in high velocity region in order to save more lives and reduce occupants' severe injury, because the relative risk increases rapidly in high velocity region over 60kph resulting in twice the risk per 5kph as shown in ***Figure3.*** And also the increase of head and neck injuries should be seiously considered when conventional driver or passenger airbags are deployed just after occupant's forward movement is produced by AEB system activation in high velocity crash from the viewpoint of passive and active safety system integration.

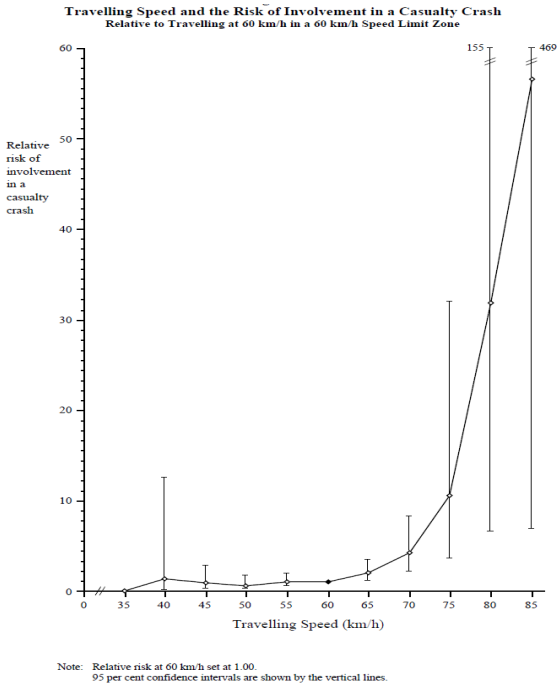


Figure3. Traveling speed and the risk of involvement in a casualty crash.

The main purpose of this paper is to improve both AEB and passive safety system to minimize the occupants' severe injury in the high velocity crash when the collision is unavoidble. The situation is assumed that a driver is in distraction, a vehicle is running in a sigle lane, there are another on-coming or rear lateral vehicles, etc. And the condition of the AEB activation is limited in the range of yaw rate so that the stability of vehiclecan be ensured. From this research, the appripriate PSB(Pre-Safety seatBelt) activation time was founded for reducing occupant's forward motion that affects head&neck injuries when AEB is working. Also, the reduction of crash speed and passenger behaviors are respectively compared according to different braking profile.

THE AEB SYSTEM IMPREMENTATION WITH ACTIVE AND PASSIVE SAFETY INTEGRATION

The Relation between active and passive safety system regarding AEB

AEB system primarilly helps decreasing occupants' injuries because of speed reduction in high velocity region. On the contrary, the increase of injury can be also accompanied due to the combination of occupants' faster behavior and airbag's high pressure deployment when AEB activated and then vehicle proceeded to crash, which is similar with OOP(Out of Position) situation. And if the vehicle's pitching motion is added, the injury can be amplified. Conventional airbags are not designed to cope with this situation, even though they satisfy LRD(Low Lisk Deployment) regulation in the US market. Some kinds of those airbags may give more harmful effect to occupants with their specific deployment mechanism.So, the tests and analisys were performed mainly to minimize the effect to occupants from AEB system and to reduce collision velocity more.

AEB System Configuration and Behavior Measurement Test of Dummy

In this tests, human dummy's behavior was mesured when AEB is activated. The test vehicle consists of Camera and Lidar sensor fusion AEB system, a ESC module of premium level and PSB module. When high speed test is conducted, DGPS device replaces the Lidar sensor because or it's short detecting range.Hybrid-3 5% and 50% dummies were used considering the coditions of US-NCAP frontal and Euro NCAP offset crash test mode. There are much difference on the behavior between dummy and human body when the acceleration under 1g occurs. THOR dummy would be better for this test, if possible. Thus, the timing and relative motion of dummy were focused on when AEB is working with different parameters. Dummy is seated in passenger seat because the motion of dummy in driver seat is smaller with the driver grabing steering wheel in the real situation. The PAB(Passenger Air Bag) deployment area is marked with vertical line and the movement is visually verified by video records as shown in ***Figure4***.

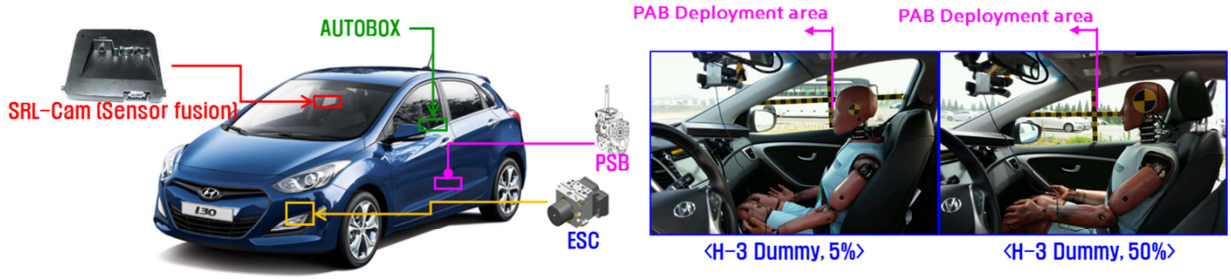


Figure4. System configuration, dummy seating and PAB deployment area.

The PSB Activation Condition for Reducing Occupants' injuries

<u>The Occupants' Injuries from Air bag Deployment</u> In the US NCAP and Euro NCAP crash test protocol, the test is carried out in the constant speed, 56kph and 64kph, respectively. Thus, the dummies are seated statically and there's no relative behavior of dummies with vehicle to the blink of crash. However, the deceleration of vehicle by 1g is generated by emergency braking in case of the AEB equipped one when the collision is expected, and therefore, dummy can get the relative acceleration and moves forward in the vehicle. Also, the vehicle can get pitching motion by the braking and if it collide with frontal car in this situation, the airbag can directly impact the passenger's head and chest causing more amplified effect as shown in ***Figure5***. Even if there's no direct impact due to the small airbag size or a passenger seated in the rear position on the seat track(i.e. H-3 50%), the head and neck injury can be increased by the combination of pitching motion and accelerated head loading on airbag cushion. Especially, PAB modules for US market tend to be designed bigger and closer to the passenger in order to satisfy H-3 50% unbelted frontal test mode. In this case, the distance between airbag deployment region and H-3 5% dummy becomes closer and the bad effect on the passenger's injury also increases.

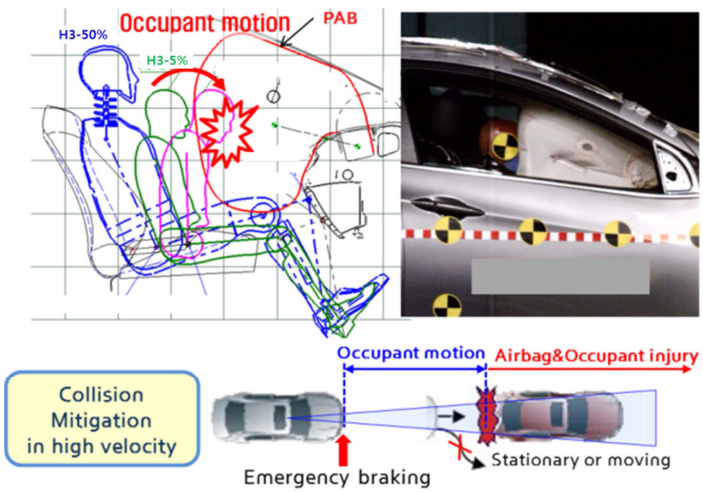


Figure5. AEB activation and the mechanism of head & neck injuries generation.

<u>The Dummy's Behavioral Characteristic according to PSB Activation Time</u> The tests are carried out to study the dummy's behavioral characteristic and to find the last PSB full retraction time so that the dummy's forward motion can be minimized. The test conditions are vehicle's running speed of 85kph and collision velocity of 50kph against stationary target. Firstly, dummy's behaviors were compared in cases of no retraction, the same PSB activation time with full brake by AEB. From the results, dummy was not effectively restrained due to the PSB actuator delay and increased load by relative acceleration. The PSB trigger time and PSB belt tension graph shows this in ***Figure6.*** Also, the time interval between full brake and maximum forward movement of dummy was measured by video and travel calculation. In the next tests, the PSB trigger time was advanced by the time gap considering the maximum forward movement time expressed as below:

Maximum forward movement time

= Signal transfer time (CAN delay) + PSB actuation delay + Dummy's behavioral moving time (1).

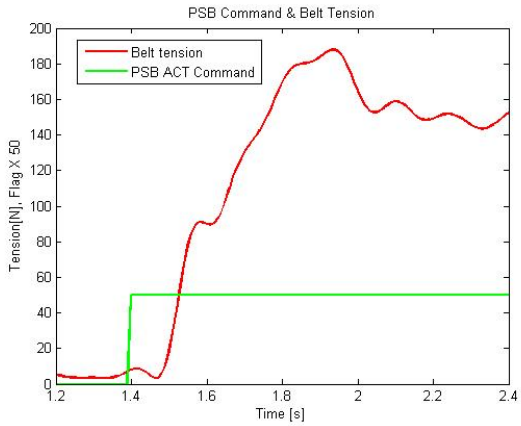
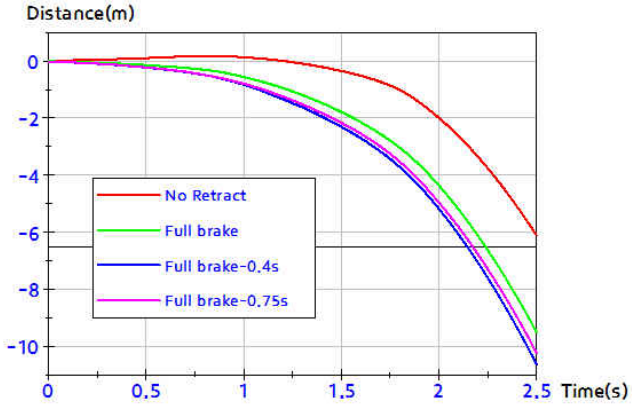


Figure6. The belt tension of PSB in Shoulder and Maximum forward movement time.

PSB actuation delay is defined that the time from it's trigger to reaching to maximum load of belt tension in static test and was measure 250ms. Dummy's behavioral moving time was 400ms, which is almost the same with the belt load reached maximum value shown in ***Figure6.*** Thus, PSB activation time was set 400ms advanced to full brake time. Additionally, the AEB tests were done in conditions of varying PSB activation time by 750ms prior to full brake, same time with pre-brake and 300ms prior to pre-brake.

From the test results in ***Figure7***, there's not much differences on dummy's forward movement when PSB is triggered before the 400ms prior to full brake. Dummy's head moves forward by 120mm with no PSB retraction, whereas, it moves about 50mm and 30mm with the trigger time of full brake and 400ms in-advance test case, respectively. If PSB is activated in the same time of full brake, dummy's head invades the PAB deployment area and then it can additionally goes further by crash impulse before airbag is fully deployed. It can be clearly expected that airbag impacts occupant's head resulting in head & neck injury increase. In case of real crash in the field, human's head would have more forward motion.

(a) Position of dummy at the moment of collision in different PSB activation time(video capture).



(b) Relative displacement of dummy's head from the AEB activation time.

Figure7. Dummy's behavior according to PSB activation time.

Figure8 shows the belt tensions in different cases, such as no retraction, various PSB activation time and pre-bre-brake profile(explained in next section).All of the belt load reach their peak almost same time which is caused by full brake, not by the first trigger time. It would be effective to reduce the forward motion of dummy befor the belt load rise up to it's peak.

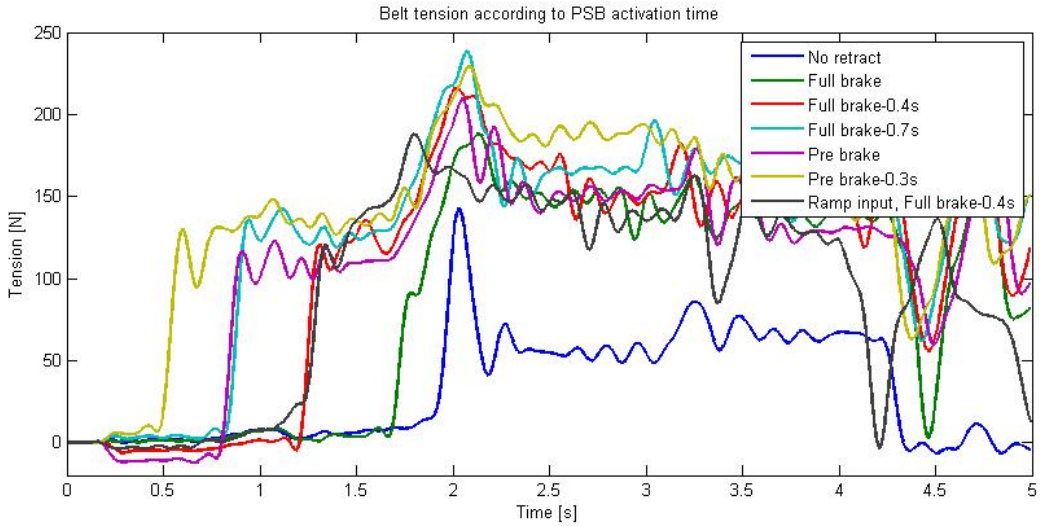


Figure8. Seatbelt tension with various PSB activation time.

It can be concluded that PSB can efficiently help preventing PAB from giving direct impact to occupant's head or reducing head & neck injury if it is triggered at least 0.4s before full brake is engaged. This can be applied to all range of vehicle velocity because there're similar dummy's behavioral characteristics according to different vehicle speed with the same amount of full brake.

The AEB Braking Profile for Reducing collision velocity

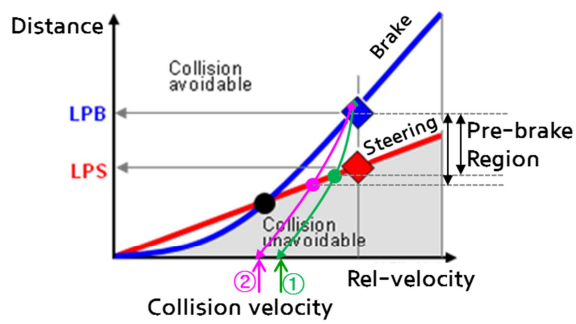
<u>AEB Control Logic</u> LPB(Last Point to Brake) and LPS(Last Point to Steer) are the time or relative distance to avoid collision about forward target vehicle by emergency braking and by steering control, respectively. Those physical quantities are illustrated in ***Figure9 (a)*** and the equations are Eqs. (2~4). Eq. (4) stands for the TTC at each collision avoidable distance and AEB system transmits the command signals to ESC following the control logic in ***Figure9 (b).***

As shown in ***Figure10,*** the collision avoidable distance by braking is shorter than the one by steering control in low velocity region and vice versa in high velocity region. The AEB control login in the test uses only full breke in low speed. In high speed, pre-brake is applied from LPB to LPS and, full brake after passing through LPS.This is for reducing frequent AEB system activation in the field by making the maximum braking at the final moment of collision avoidance by lateral control.

$$d_{brake} = -\frac{v_{rel}^2}{2a_x} \qquad (2).$$

$$d_{steer} = -v_{rel}\sqrt{\frac{2s_y}{a_y}} \tag{3}$$

$$d_{brake} = -\frac{v_{rel}^2}{2a_x} \Rightarrow t_{LPB} = \frac{d_{brake}}{-v_{rel}} = -\frac{v_{rel}}{2\mu g}$$
$$d_{steer} = -v_{rel}\sqrt{\frac{2s_y}{a_y}} \Rightarrow t_{LPS} = \frac{d_{steer}}{-v_{rel}} = \sqrt{\frac{2s_y}{\mu g}} \tag{4}$$



Velocity region	Collision level	Brake profile	
Low	Avoidance	TTC < t_{LPB}	Full brake
High	Mitigation	t_{LPS}< TTC < t_{LPB}	Pre brake
		TTC < t_{LPB}	Full brake

(a)LPB, LPS graph *(b) Control logic*

Figure9. Braking time and AEB Control logic

<u>Collision Velocity Reduction According to Pre-braking Profile</u> Generally, pre-brake with low deceleration is used in AEB system in order to raise the initial cylinder pressure of ESC and to make it easy for driver to avoid front obstacles by string control as the collision risk increases after ADAS sensors detect them. After that, full brake is engaged at the TTC condition when collision is unavoidable. With this scenario, the collision speed is mitigated in high velocity region. In this study, two kind of pre-brake profiles are applied without the change of pre and full braking time. One is step input with0.2g and the other is ramp input from 0g to 1g which is expressed by Eq.(5):

$$A_{brake} = \frac{1}{t_{LPS} - t_{LPB}}(t - t_{LPB}) \tag{5}$$

It seems to be obvious that the crash speed would decrease and the braking distance become shorter in the case of ramp input as shown in ***Figure11.***

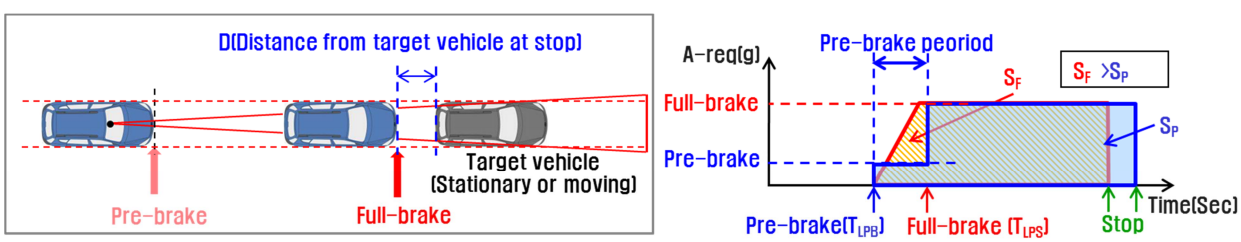


Figure11. Braking point and the concept of braking profile.

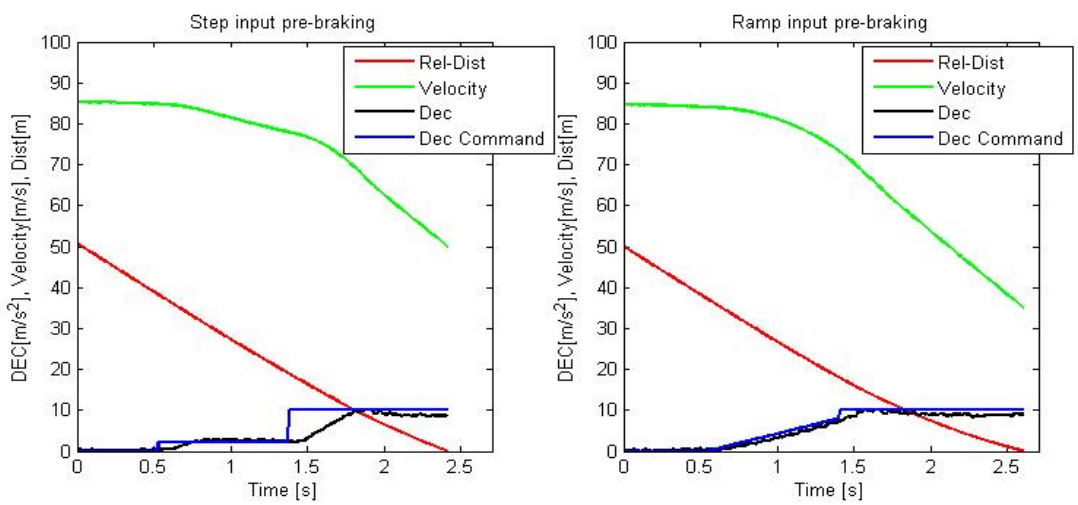
In this tests, the DGPS device is used for mesuring distance to crash point becase of the short detecting rage of Lidar sensor. With the same pre-braking time, the crash speed of ramp input decreases by 15kph in comparison to the step input case as shown in ***Table1***.When the crash occurs in those two conditions, whether PAB is deployed or not can be changed according to collision velocity. And the faster the the initial velocity is, the more the reduction of velocity beome because pre-brake time lasts longer. If this ramp input braking profile is applied to AEB logic, the collision avoidable vehicle speed can be raised maintaing the marketability same as step input. And also the probability of quality problem like frequent or unnecessary emergency braking activation can be reduced because the initial braking time can be set to later time if the collision speed is tuned same each other. This priciple is explained well in ***Figure9(a)*** with the line number ① and ②. In the ② case with ramp input, the reduction of velocuty increase between LPB and LPS, and finally drash speed goes down.

Table1.

Collision velocity according to pre-braking profile.

Braking profile	Initial velocity	Collision velocity	Reduction of crash velocity
Pre-brake 0.2g	85kph	50kph	35kph
Ramp input	85kph	35kph	50kph

Pre-fill and pre-brake input play a roll to make the cylinder pressure of ESC raise faster to full brake level. There's about 450ms delay of full deceleration after the moment when 1g step input command is transferred to ESC, whereas the vehicle deceleration follows the ramp input and full brake signals well in ***Figure12***. This mechnism mainly contributes to decreasing more collision velocity with ramp input. If ADAS sensors and communication performance in vehicle is improved in the future, the collision velocity would be minimized by using feedbak control.



(a) Pre brake : 0.2g Step input ***(b) Pre brake : Ramp input***

Figure12. Vehicle behavior according to pre-braking profile.

Head Acceleration According to Pre-braking Profile The relative acceleration at crash moment affects the occupant's head & neck injuries. In the NCAP frontal crash test, dummy has almost zero acceleration when the test vehicle impacts the barrier, but it gets relative acceleration at the moment with the AEB activation, which varies depending on braking performance and control level. When ramp type of pre-braking profile is used, the rise rate of acceleration and it's peak value are small compared with step input as verified in ***Figure13***. The passenger can also has soft feeling with small jerk. Ramp input signal can be expected to decrease occupant's head & neck injuries.

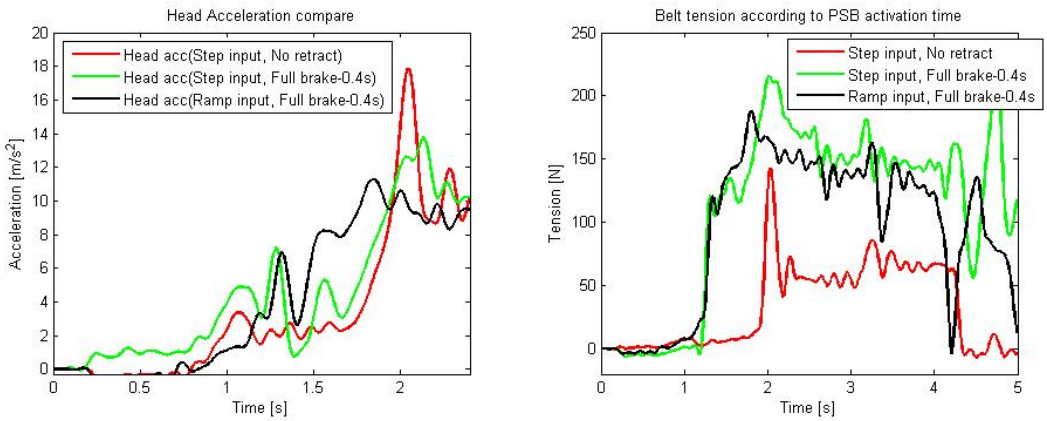


Figure13. Head acceleration and belt tension according t pre-braking profile.

CONCLUSIONS

In the viewpoint of active and passive safety integration, this study aims to find appropriate PSB activation time so that the bad effect by AEB system can be removed and to reduce the final crash speed after AEB is activated by enhance the pre-braking profile. As a result, it was found out that dummy's forward motion is sufficiently decreased when PSB is activated at least 0.4s before full brake time, which can be changed by PSB and ESC performances. As well as this, the pre-brake profile of ramp input is more efficient in reducing crash speed and head's acceleration rather than constant one.

H-3 dummies used in this research have much difference with human body in behavioral aspects. The same tests targeting human or THOR dummy should be carried out to get more accurate data. And the research about various braking profile and feedback control logic to improve AEB performance considering occupants' injuries and marketability is needed in the future.

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