DESIGN SENSITIVITY STUDY OF PASSENGER AIRBAG SHAPE TO MEET HEAD RESTRAINT PERFORMANCE FOR DIFFERENT OCCUPANT SIZE IN FRONTAL IMPACT

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ABSTRACT

Range of restraint performance needs to cover different occupant restraint conditions and occupant size in accordance to government regulation and NCAP tests. It should be effective in real-world safety also. There are several ways to accomplish the required safety performance. For example, adaptive system of airbag and belt load-limiter could be adjusted (i) depending on the occupant size, sensed by weight sensor and (ii) due to change in restraint condition, when buckle latch switch is introduced.

The present study focused on the sensitivity of the airbag shape on occupant head restraint performance and investigated the possibility to meet the required level of restraint performance by manipulating only the airbag shape with the help of airbag stiffness performance diagram.

In conclusion, to achieve the near optimum head restraint performance, by introducing S-shape in vertical direction at the center of the airbag instead of a Flat-shape airbag, the airbag stiffness can be tuned to meet performance requirements of two different size dummies AM50 and AF05 simultaneously.

INTRODUCTION

At present, a lot of NCAP and regulations tests are performed to improve the vehicle safety performance.

These evaluation procedures are not only based on vehicle structural deformation but also on the level of various types of occupant injuries at different body region such as head, neck, thorax, knee-femur, etc.

Further, in US, there are different test procedures based on the size of the occupant (AM50, AF05) and the restraint conditions (belted and unbelted).

To meet the required level of safety performance satisfying these variety of crash test conditions, not only the vehicle crash pulse and the amount of cabin intrusion but also the performance characteristics of the occupant restraint system (airbag, seatbelt) to be designed within the specified space around the occupant are very important factors [1]. Recently, following restraint systems are applied in vehicles to meet the different modes of crash with different occupants and restraint conditions.

Multiple operation level of an adaptive airbag and belt load-limiter system could be adjusted

(i) depending on the occupant size, sensed by weight sensor
(ii) due to change in restraint condition, when buckle latch switch is introduced

These procedures, using occupant sensing information, can control the characteristics of restraint performance of airbag and seatbelt.

The present study focused on the sensitivity of the airbag shape on occupant injury reduction possibility and investigated the possibility to meet the required level of restraint performance by manipulating only the airbag shape.

METHOD

STEP1: PRELIMINARY DESIGN STUDY

The amount of energy absorbed by an airbag changes due to many factors, for example the impact speed, the occupant size and the occupant restraint condition, such as belted or unbelted.

From the airbag performance requirement view point, the airbag should absorb sufficient amount of energy of the head and the thorax of the occupant as it moves towards the windshield from the start of the crash.

The layout of the interior of the vehicle and the relative initial position of the AM50 and AF05 occupants are shown in Figure 1.

The relation of the distance between the occupant head and the windshield is such that, the taller is the size of the occupant, the higher is the position of the restraint region on the airbag for the

occupant head which comes closer to the windshield.
On the other hand, the smaller is the occupant, the lower is the position of the restraint region for the head which remains further away from the windshield resulting in more head restraint stroke in between the head and the windshield (Figure 2).
Again, so far as the level of energy absorbed by the airbag is concerned, it is more for the bigger occupants due to increase in mass of the occupant. Furthermore the amount of stroke is less for a taller occupant. Consequently the airbag should be stiffer. However, for lower region of the airbag, the required amount of energy to be absorbed is less due to the relative decrease in mass of the smaller occupant to be supported and consequently the required stiffness of the airbag should be low because the amount of stroke is more for a shorter occupant.
Further, if the level of the biomechanical tolerance related to AF05 population is usually lower than those for relatively bigger occupants corresponding to AM50 population [2], restraining at lower level airbag stiffness will be preferable.
Hence, if the degree of the restraint force and the stiffness of the airbag could be controlled, with respect to (i) the relative initial position, (ii) the target region of the airbag and (iii) the size of the occupant, a proper balance could be achieved (Figure 3).

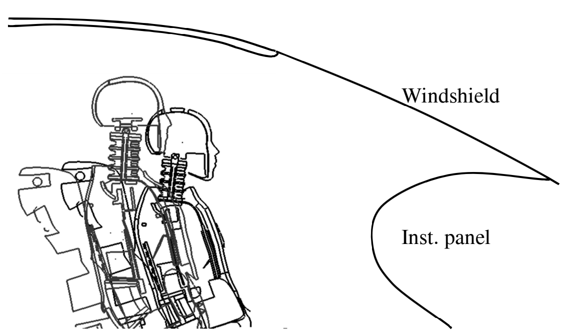


Figure1. Vehicle interior layout of a typical mid-size sedan with AM50 and AF05

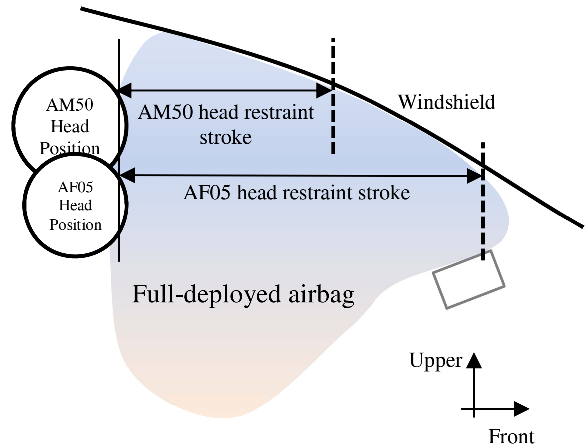


Figure2. Comparison of the head restraint stroke for AM50 and AF05 inside a mid-size sedan

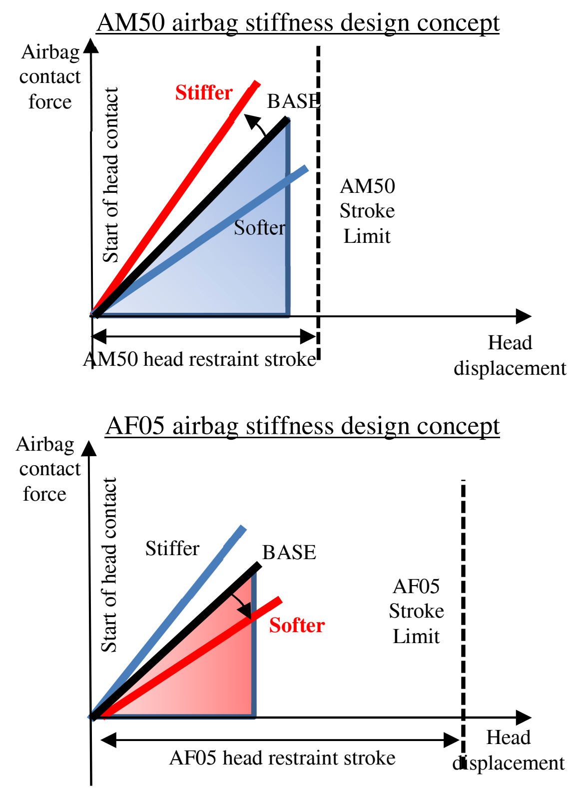


Figure3. Schematic diagram of airbag stiffness design concept to suit AM50 and AF05

STEP2: CAE SIMULATION

Simulation scenario

This section will describe about the simulation results to investigate the characteristics of the restraint force of the upper and lower halves of the airbag as mentioned in the previous section. In general, the vent-hole size, and inflator power are adjusted to manipulate the overall pressure inside

the airbag. Local airbag pressure is difficult to control with single chamber airbag.
However, incorporating a valley at the center of the airbag can partially control the local airbag restraint force [3].
The present study focused on the depth of the airbag at the center line. As the amount of head displacement of the AM50 and AF05 dummies can be adjusted by the depth of the valley at the center of the airbag, the degree of design flexibility to change the level of the restraint force acting on the head is investigated.

Simulation condition

Regarding FMVSS208 and US-NCAP test performance conditions among various other stipulated test conditions, the following two test cases are selected.
・56km/h belted AF05 (belted-AF05)
・40km/h unbelted AM50 (unbelted-AM50)
The layout, crash pulse and other related test conditions are based on the data of a typical mid-size sedan in US market. Explicit FE code PAM-CRASH™ solver is used.

Design parameter
Airbag design

CAE based parametric study is carried out to study the effect of the shape of the stitching at the central valley and the vent-hole size of the airbag.
The wavy stitching line (S-shape) , and the straight stitching line (Flat-shape) are the two design shape parameters at the center of the valley, as shown in figure 4 and 5.
In S-shape, in accordance with the position of restraint of the different size of the occupants, the depth of valley at the center of the airbag is varied to increase the level of head-restraint for the AM50 occupant and to reduce the same for AF05 occupant. To be more specific, the depth of the valley is varied with respect to occupant size to increase the degree of restraint, it is bulged out towards the occupant for AM50 and it is bulged away from the occupant for AF05.

The parameters that are changed in this study are shown below.
・Shape at the center of the valley
（Flat-shape, S-shape）
・Vent-hole size (V/H)
（S; Small, M; Medium, L; Large）

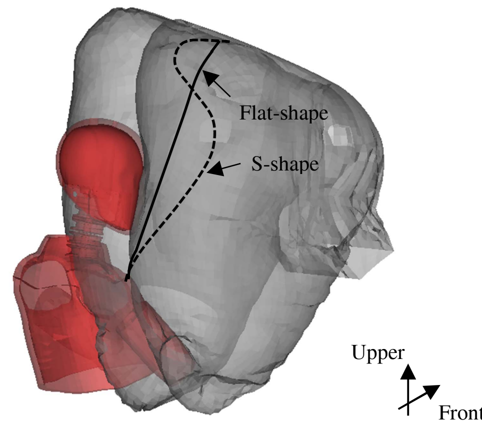


Figure4. Isometric view of present 3D airbag shape

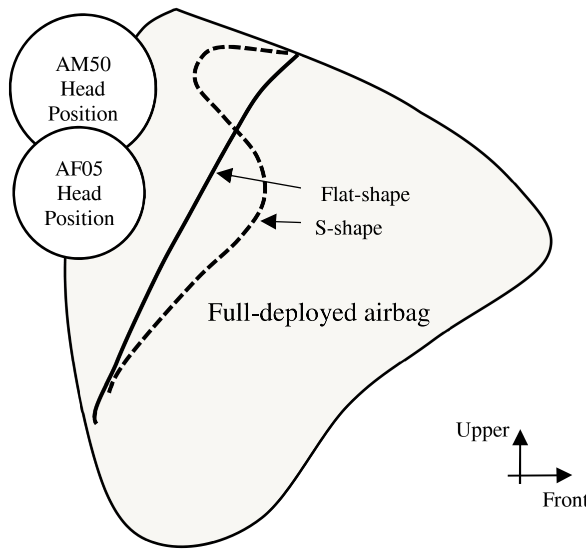
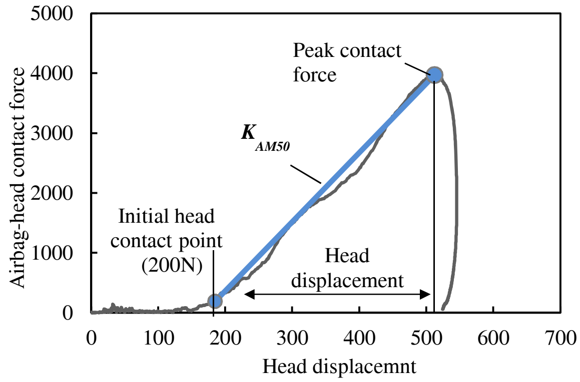


Figure5. Side view of the airbag shape showing relative position of the stitching line at the center of the valley

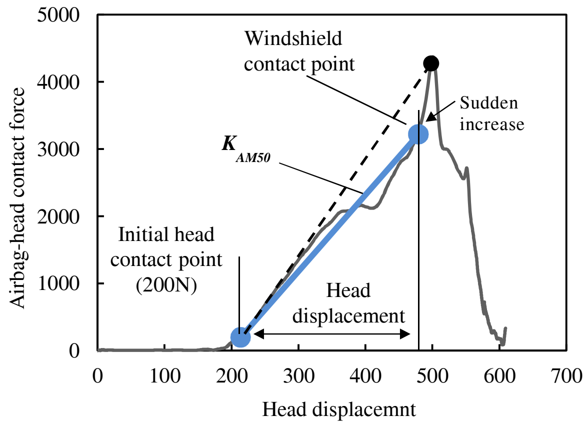
Airbag stiffness

The effect of variation of airbag stiffness, denoted by (K_{AM50}, K_{AF05}), is studied. In figure 6 a-b, the vertical axis shows the contact force of the dummy head with the airbag and the horizontal axis is the displacement of the head of the dummy.
The airbag stiffness (K_{AM50}, K_{AF05}) is defined as and calculated from the slope of the peak of the contact reaction force (Figure 6-a). The initial measuring point of the stiffness is defined as the point where the reaction force reached 200N level. Again, when the head almost contacts the windshield, in such cases, the final measuring point of the stiffness is defined at the point where the slope of the contact reaction suddenly increases (Figure 6-b).

$$K_{AM50,AF05} = \frac{Airbag\ contact\ maximum\ force}{Head\ displacement}$$



(a) Without head contact with windshield



(b) With head contact with windshield

Figure6 a-b. Definition of airbag stiffness

Result

(i) Comparison of airbag shape

In figure 7, F-S characteristics of the head-airbag contact force (F) vs. the head displacement (S) is plotted for belted-AF05 and unbelted-AM50 conditions. Comparing the results of AM50 and AF05, one can estimate the difference in the amount of energy absorbed due to the difference in mass of the dummies and the restraint conditions (belted and unbelted).

As shown in figure 7, comparison of the 2 airbag shapes (Flat-shape and S-shape) indicate that 14% reduction of the peak contact force for AF05 and 5% increase in contact force for AM50 respectively. As shown in figure 8 a-b, visualizing and comparing the amount of penetration of S-shape and Flat-shape airbag, the head penetrates deep into the S-shape airbag while head is stopped early at the stitching line of the Flat-shape airbag resulting in direct normal contact.

This direct contact for Flat-shape airbag resulted in some amount of increase in head-airbag contact force.

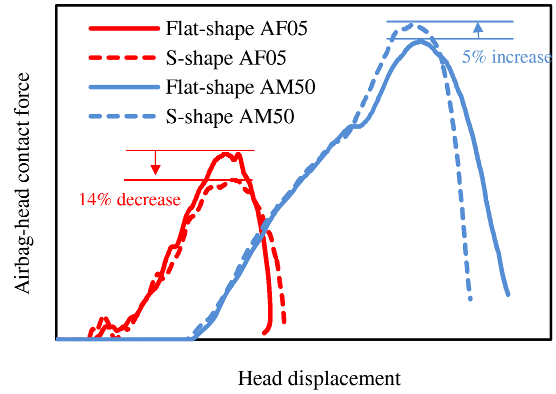
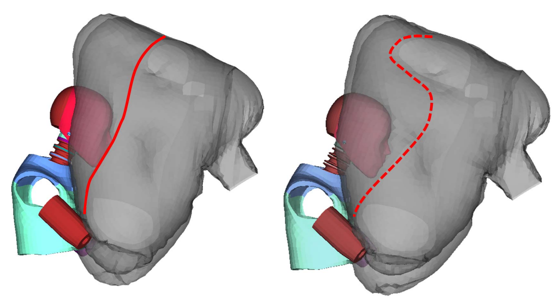
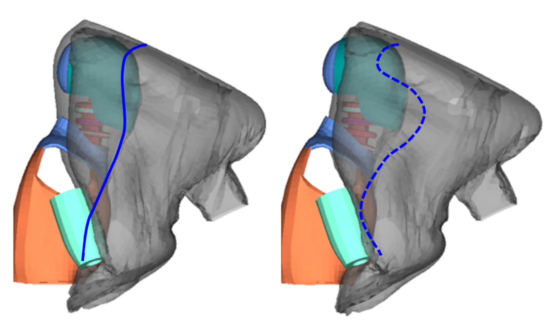


Figure7. Comparison of the head contact force (F) – displacement (S) characteristic for Flat-shape and S-shape airbag in belted-AF05 and unbelted-AM50 conditions



(a) Flat-shape *(b)* S-shape

Belted-AF05 condition



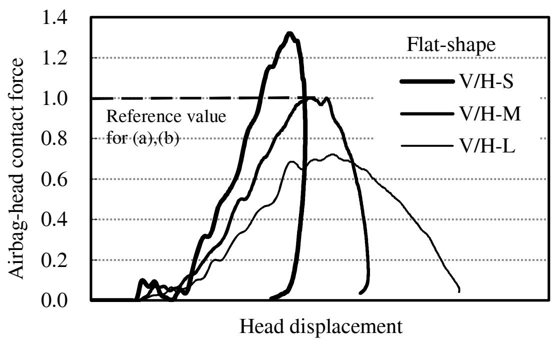
(c) Flat-shape *(d)* S-shape

Unbelted-AM50 condition

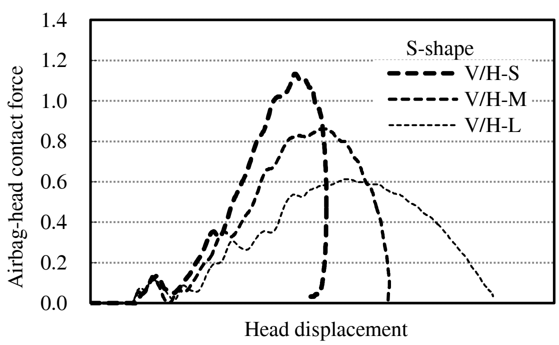
Figure8 a-d. Comparison of the head excursion inside Flat-shape and S-shape airbag in belted-AF05 and unbelted-AM50 conditions

(ii) Comparison of the vent-hole size

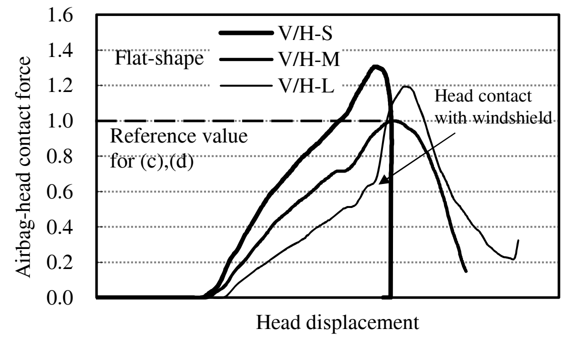
The comparison of the head contact force (F) – displacement (S) characteristic for Flat-shape and S-shape airbag for belted-AF05 and unbelted-AM50 conditions with V/H-S,M,L, are shown in figure 9 a-d. With the peak value of the airbag contact force of belted-AF05 and unbelted-AM50 in combination with Flat-shape of V/H-M airbags respectively as reference values (1.0), all the other airbag contact forces are normalized with respect to two reference values. As shown in figure 9 a-b for belted-AF05 condition, with the increase of vent-hole size, the peak value of the contact force becomes relatively low. As shown in figure 9 c-d for unbelted-AM50, the slope of the contact force decreases with the increase of vent-hole size before the start of bottoming out phase of the airbag between the head and windshield. As V/H-L, the airbag stiffness is too low at the initial phase of the head displacement, it resulted in hard contact of the head with the windshield at the final stage (Figure 10).



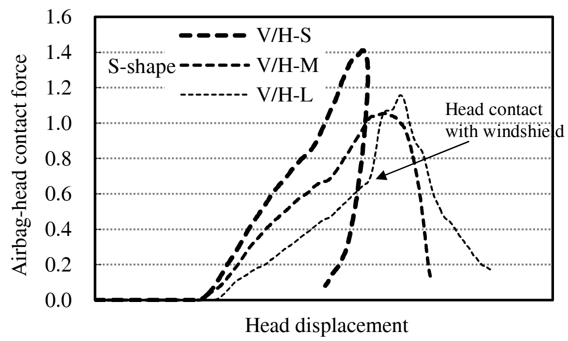
(a) Flat-shape (belted-AF05)



(b) S-shape (belted-AF05)



(c) Flat-shape (unbelted-AM50)



(d) S-shape (unbelted-AM50)

Figure9 a-d. Comparison of the head contact force (F) – displacement (S) characteristic for Flat-shape and S-shape airbag in belted-AF05 and unbelted-AM50 conditions with V/H-S,M,L,

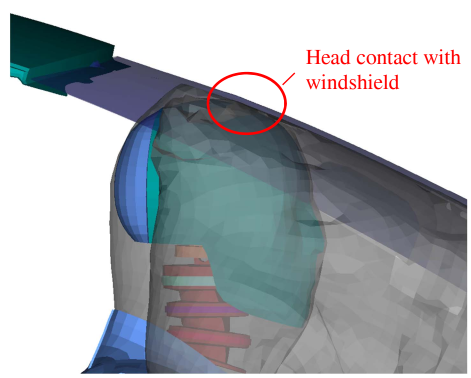


Figure10. Head contact with windshield with V/H-L airbag in unbelted-AM50 condition

(iii) Sensitivity study for airbag stiffness

Using the airbag stiffness estimation procedure as defined in the previous section, twelve simulation results are plotted in table1. With the stiffness of belted-AF05 and unbelted-AM50 in combination with Flat-shape of V/H-M airbags as respective reference values, all the other results are normalized with respect to two reference values.

Comparing the results for V/H-M with Flat-shape and S-shape airbags, the airbag stiffness is 17% lower for AF05 and 7% higher for AM50 in table1. Based on the CAE simulation results, the basic assumption that (i) the airbag stiffness will be low for AF05 and (ii) the airbag stiffness will be high for AM50, are verified.
In figure 11, the simulation results related to the variation of shape and the vent-hole size are plotted with two axes chosen as airbag stiffness, the vertical axis for unbelted-AM50 and the horizontal axis for belted-AF05.
Comparing the simulation results for different vent-hole size and airbag shapes, one can observe that the stiffness of the airbag increases both for AM50 and AF05 if the vent-hole size is made smaller for Flat-shape airbag. However, for S-shape airbag, the increase in relative stiffness is comparatively less for AF05 than compared to the amount of increase of airbag stiffness for AM50.
With V/H-L, in both of the S-shape and Flat-shape airbags, as the head hits the windshield, one can expect that, for AM50, there exists a lower bound of the airbag stiffness between the V/H-M, V/H-L airbag stiffness.
Again, to reduce the AF05 injury level, it is necessary to reduce the airbag stiffness. Therefore, an optimum region exits on the left side where AF05 stiffness tends to reduce and above the limit for AM50 stiffness due to stroke length as shown by respective vertical and horizontal arrows in the figure 11. The optimum region is shown in dotted circle at the left bottom corner in the figure 11.
In the present simulation result, it is decided that S-shape with V/H-M belongs to one of the optimum solutions, and sled tests are performed to verify it.

Table1. Comparison of airbag stiffness for different combination of airbag design parameters
(*Reference design: 1.00)

V/H	Belted-AF05		Unbelted-AM50	
	Flat-shape	S-shape	Flat-shape	S-shape
S	1.70	1.29	1.43	1.61
M	**1.00***	0.83	**1.00***	1.07
L	0.65	0.51	0.76	0.77

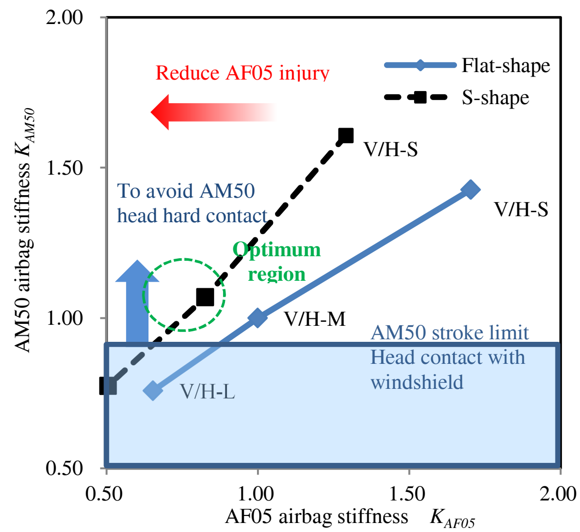


Figure11. Illustrated design procedure to achieve the optimum airbag stiffness solution

STEP3: VERIFICATION BY SLED TESTS

To confirm the findings from the CAE simulations, sled tests equipped with prototype airbag are carried out.

Test condition

Similar to the CAE simulations, the following two sets of experiments are carried out.
・56km/h belted AF05
・40km/h unbelted AM50

Airbag: S-shape with V/H-M

Results

In figure 12, the simulation and experiment results are plotted as G-S curves with head acceleration G (X-component) as the vertical axis, and head displacement S as the horizontal axis.
As good correlation is achieved between the simulation and experiment results for belted-AF05 and unbelted-AM50 conditions, the head of them are well restrained as expected.
G-S data for AM50 indicates that the head is well restrained without any hard contact.

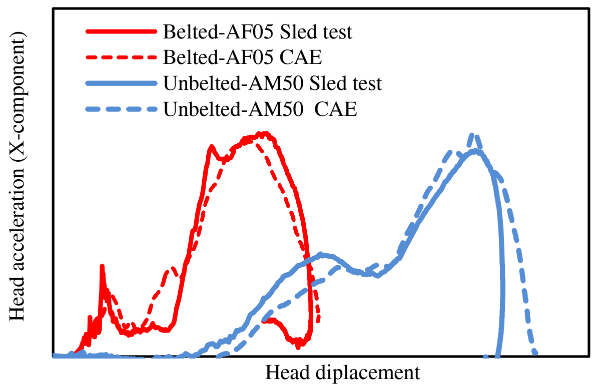


Figure12. Comparison of the X-component of head acceleration – displacement characteristic in belted-AF05 and unbelted-AM50 conditions

(a) Belted-AF05 condition

(b) Unbelted-AM50 condition

Figure13 a-b. Side view of sled tests

CONCLUSION

In the present study, with respect to difference size of occupant and the restraint conditions (belted and unbelted), in order to satisfy the head restraint performance requirement, CAE simulations and experiments are carried out.

The following conclusions are drawn to achieve the near optimum head restraint performance

(a) By introducing S-shape in vertical direction at the center of the airbag instead of a flat-shape airbag, the airbag stiffness can be tuned to meet performance requirement of two different size dummies AM50 and AF05 simultaneously.

(b) Design procedure to achieve the optimum airbag stiffness solution is illustrated with the help of airbag stiffness versus performance diagram.

Further studies are needed for the following main conditions and etc.:

(i) Type of vehicle (sedan, mini-van, SUV, etc.)

(ii) Crash configulations

(iii) Size of the occupant other than AM50 and AF05

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