Development of a Side Impact Sled Test Method using Multiple Actuators

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ABSTRACT

This paper describes a new test method for predicting Anthropomorphic Test Dummy responses to calculate injury index in side impact tests with a moving deformable barrier (MDB). Sled tests are effective in shortening the development period for more safety vehicle equipped with side impact safety devices and reducing the cost and period needed to prepare prototype test vehicles. To accomplish sled tests successfully, it is necessary to simulate the complex door deformation behavior which changes different in dummy response regions by impacting with a MDB. Conventional sled test methods simulated roughly the intrusion of the entire door using a single actuator. The methods limited the dummy response regions which can be predicted because it was difficult to simulate the door deformation behavior.
The new sled test method using the **A**dvanced **S**ide **I**mpact **S**imulator (ASIS) was developed by identifying the door intrusion behavior needed to predict each dummy response. Multiple actuators were used to simulate door deformation behavior of each dummy response region. High-output actuators were used to simulate the intrusion of the rapidly accelerating door in the initial phase. A feedback control function was used to regulate the door and seat velocities of the actuators so that they would simulate the input velocity profile even if they were acted on by the reaction force of the dummy or other parts. A comparison of dummy responses obtained in ASIS tests and in vehicle tests showed good agreement. This confirmed that the new test method is capable of predicting each dummy response with high accuracy.

INTRODUCTION

There are two principal factors that determine dummy responses in side impact tests. One factor is the body structure of the impacted vehicle. The body structure reducing the body deformation and the crash forces applied to the dummy result in reducing dummy responses. Another factor is side impact safety devices such as a door trim and a side airbag. The devices reducing the crash forces applied to the dummy result in reducing dummy responses. It is essential that the devices are effective in various types of real-world accident configurations. [1]
Developing more safety vehicle equipped with side impact safety devices involves a process of trial and error in order to find the optimum combination of design variables. If that process could be carried out in sled tests, it would be possible to reduce the cost and period needed to prepare prototype test vehicles. Toward that end, various methods of conducting side impact sled tests have been developed to date. [2] To accomplish sled tests successfully, it is necessary to simulate the complex door deformation behavior which changes different in dummy response regions by impacting with a MDB. Conventional sled test methods simulated roughly the intrusion of the entire door using a single actuator. The methods limited the dummy response regions which can be predicted because it was difficult to simulate the door deformation behavior. Moreover, in order to predict dummy responses with more regions, the input profiles, initial layout and initial door metal shapes must be modified, thereby complicating the design of the sled test and making it difficult to obtain sufficiently reliable test results. [3]
This paper describes a new test method predicting each dummy response region. Vehicle test data are also presented to verify the prediction accuracy of the dummy responses obtained with the proposed method.

TEST METHOD

The key factors used in predicting dummy response in this test method are the door deformation, which applies force to the dummy via the door trim and the side airbag, and the deformation of the seat that houses the side airbag. However, the door deformation is complex, and the intrusion depth toward the interior of the vehicle varies from one part of the door to another. To take such differences into account, ASIS shown in Figures 1 and 2 was developed. Multiple actuators were used to simulate door deformation behavior of each dummy response region. Each actuator incorporated a hydraulic brake device for simulating the door intrusion velocity. Another actuator was also used to simulate seat behavior in the lateral direction. These multiple actuators were synchronized and controlled based on the operating velocity profile input into each one.

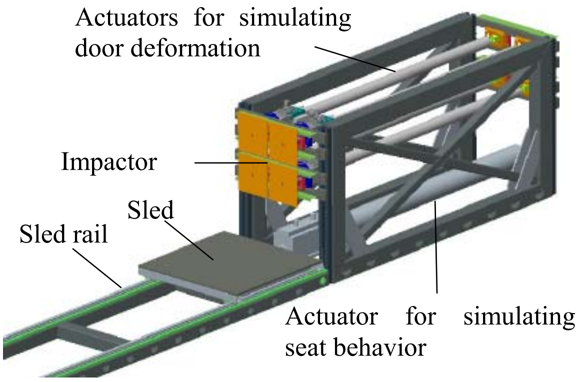


Figure 1. Structure of ASIS.

Figure 2. Photo of ASIS.

1. Simulation of complex door deformation

The principal dummy responses are related to chest deflection, abdominal deflection, abdominal force and pelvic force. The door deformation characteristics needed to predict dummy responses in these regions were summarized, and the optimum positions of the actuators for simulating the characteristics were determined.

In this study, computer simulations of dummy responses by using a FE dummy model were conducted to optimize the number and positions of the actuators. The chest, abdomen, pelvis and knee were selected as typical regions where impact forces are input to a dummy. The door deformation was simulated using from one to four actuators. Then the obtained dummy responses were compared with corresponding data recorded in vehicle tests. Figure 3 shows the input conditions considered in the simulations; Figure 4 presents the input profiles to each region resulted from previously conducted vehicle tests; and Figure 5 shows the relationship between the dummy responses and the number of actuators used in the computer simulations. The results in Figure 5-a) indicate the difficulty in simulating the dummy responses in all four regions with a conventional approach using only one actuator. Moreover, door deformation extending from the chest to the pelvis must be simulated in order to predict the dummy responses of the chest and abdomen (Figure 5-b), 5-c)). In order to predict the dummy responses of the pelvis, it is necessary to simulate door deformation as far as the knee, in addition to the chest, abdomen and pelvis regions (Figure 5-d)).

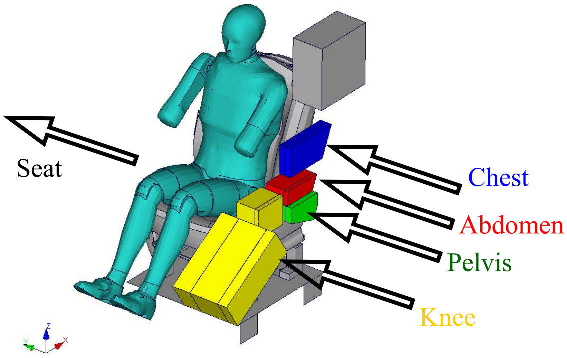


Figure 3. Input conditions of door and seat for computer simulation.

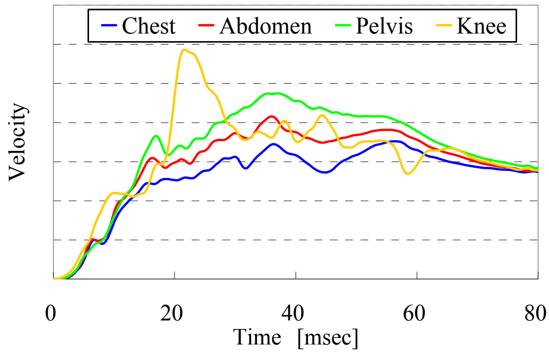


Figure 4. Input profiles for computer simulation.

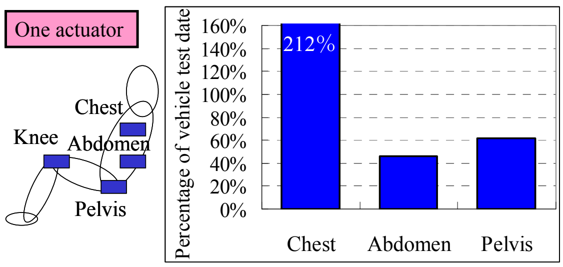


Figure 5-a). One actuator

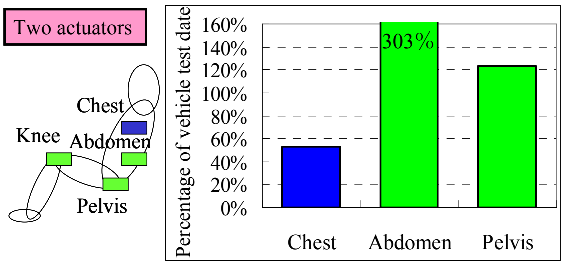


Figure 5-b). Two actuators

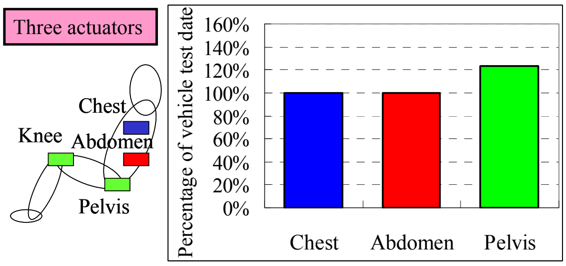


Figure 5-c). Three actuators

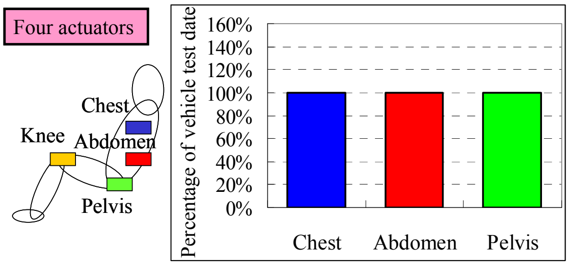


Figure 5-d). Four actuators

Figure 5. Relationship between number of actuators and dummy responses in computer simulation.

However, door deformation in the regions corresponding to the chest, abdomen and pelvis cannot be simulated simply by using three actuators. To simulate intrusion of rapidly accelerating door, it is necessary to use an actuator with a large outer diameter. That would not allow separate intrusion to be applied to the chest, abdomen and pelvis. Accordingly, the actuators for the chest and pelvis regions were used to produce door deformation corresponding to the abdomen region. Two actuators for the chest and pelvis regions were used to apply to the chest, abdomen and pelvis of dummy. In addition, one actuator was used to apply force to the knee region, which contributes substantially to pelvis response.

Figure 6 presents profile of the door deformation in the chest, abdomen and pelvis regions in a vehicle test and profile in result of simulating the door deformation by using two actuators in the ASIS. It measured at 10-msec. intervals from 0 to 60 msec. The vehicle test data indicate that door intrusion depth changes different in the chest, abdomen and pelvis regions. In order to simulate the door deformation by using two actuators for the chest and pelvis regions, the position of division of the abdomen region was essential. It was determined by two factors. One factor is simulation of profile change in door deformation of the each region. The position was determined in Figure 6 to reduce the differences of profile between vehicle test and ASIS simulation most. Another factor is the relative position of the MDB to the door. The bumper and taper of the MDB is the strong relationship with the door deformation.

Figure 7 shows the ASIS impactor that was devised on the basis of the simulation results in Figure 5 and 6. The impactor was divided into three sections in order to simulate the different intrusion depth of the door by using three actuators corresponding to the chest, pelvis and knee regions. The impactor simulates the shapes of the door metal parts.

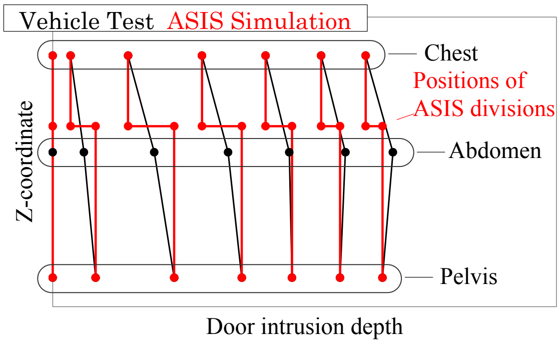


Figure 6. Comparison of profile of door deformation in the vehicle test and result of simulation in the ASIS.

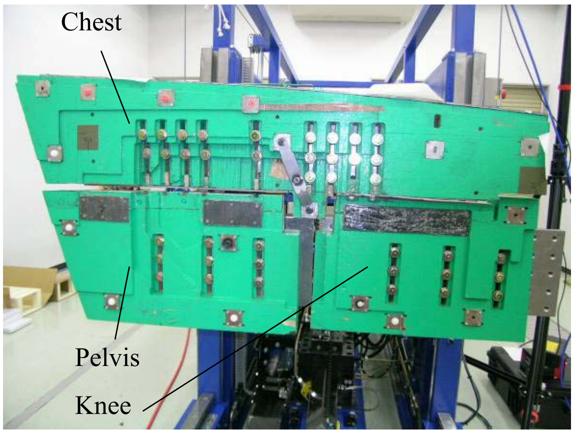


Figure 7. ASIS impactor.

2. Simulation of intrusion of rapidly accelerating door in the initial phase

Figure 8 shows the door and seat intrusion velocities recorded in a vehicle test and the input profiles of an ASIS test. As seen in Figure 9, there is a space between the door trim and the seat in the initial phase from 0 to 20 msec. The side airbag deploys in this initial phase. In order to simulate dummy responses, it is necessary to simulate the intrusion of the rapidly accelerating door, the deployment behavior of the side airbag and the effect of the side airbag on reducing the force input to dummy.

To accomplish that, the high-output actuators were used. In addition, the actuators were reduced in size and mass because multiple actuators were used. These changes made it possible to simulate the intrusion of the rapidly accelerating door in initial phase, as shown in Figure 8. As a result, the simulated deployment behavior of the side airbag agreed with the vehicle test results, as seen in Figure 10. The deployment behavior higher than shoulder was different because the chest actuator was also used for the region higher than shoulder. But the deployment behavior of each dummy region agreed well.

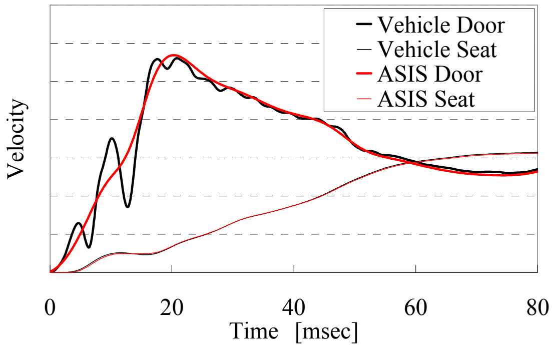


Figure 8. Velocity profiles door and seat.

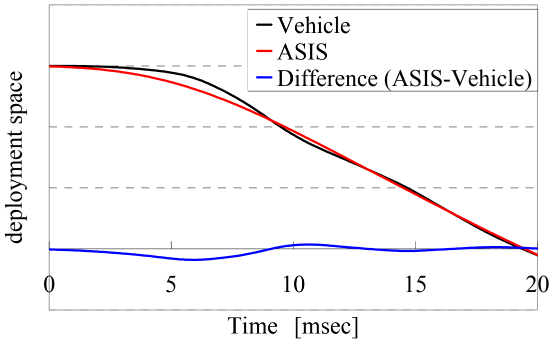


Figure 9. Deployment space of side airbag.

Figure 10. Side airbag deployment behavior.

3. Simulation of door and seat velocities by a feedback control function

A feedback control function was used to regulate the door and seat velocities of the actuators so that they would simulate the input velocity profile even if they were acted on by the reaction force of the dummy or other parts. Contact with the dummy or other parts causes the actuator velocities to decline substantially. A feedback control function was used for increasing the acceleration force of the actuators instantaneously so as to enable them to operate according to the input profiles. As a result, the door and seat velocities were simulated.

TEST SETUP

In the conventional methods, the velocity profiles, part shapes and layout, and other elements input for the purpose of predicting dummy responses have tended to differ from vehicle tests. One feature of this new method is that the input velocity profiles, part shapes and layout are all designed to agree with those of vehicle tests.

1. Design of door and seat input profiles

The input profiles were designed according to the acceleration data of previously conducted vehicle tests and computer simulations. A low-pass filter was used to remove the high acceleration components that could not be reproduced because of the limitations of the test equipment.

2. Design of impactor

The impactor simulates the shapes of the door metal parts. The impactor was divided into three sections. Two actuators for the chest and pelvis regions were used to apply to the chest, abdomen and pelvis of dummy. In addition, one actuator was used to apply force to the knee region, which contributes substantially to pelvis response. The position of division of the abdomen region was determined by two factors. One factor is simulation of profile change in door deformation. The position was determined in Figure 6 to reduce differences of shape between vehicle and ASIS most. Another factor is the relative position of the MDB to the door. The bumper and taper of the MDB is the strong relationship with the door deformation.

3. Design of part shapes and layout

Table 1 lists the parts needed to conduct a test. The part shapes and the layout were all designed to agree with those of vehicle. The asterisk (*) shows that the parts is not needed in the case with the vehicle targeted by the verification of this method.

Table 1. List of the parts

Parts	Needed or Not
Seat	Needed
Side Airbag	Needed
Door Trim	Needed
Seat Belt	Not Needed*
Curtain Airbag	Not Needed*
B-Pillar	Not Needed*

RESULTS AND DISCUSSION

1. Test configuration

ASIS tests were conducted in order to verify the results in comparison with vehicle test data. Table 2 lists the test configuration conducted.

Table 2. Test configuration

IIHS	EuroNCAP
MDB	MDB
50 km/h	55 km/h
Driver	Driver
SID-IIs Level D	ES-2

2. IIHS

The vehicle test data and the ASIS test results were compared with regard to the SID-IIs dummy responses under the IIHS configuration.

Figure 11 shows the door velocity profile in the vehicle test and the velocity profiles input into the ASIS actuators. Figure 12 compares the door deformation of the chest, abdomen and pelvis regions between the vehicle test and ASIS test.

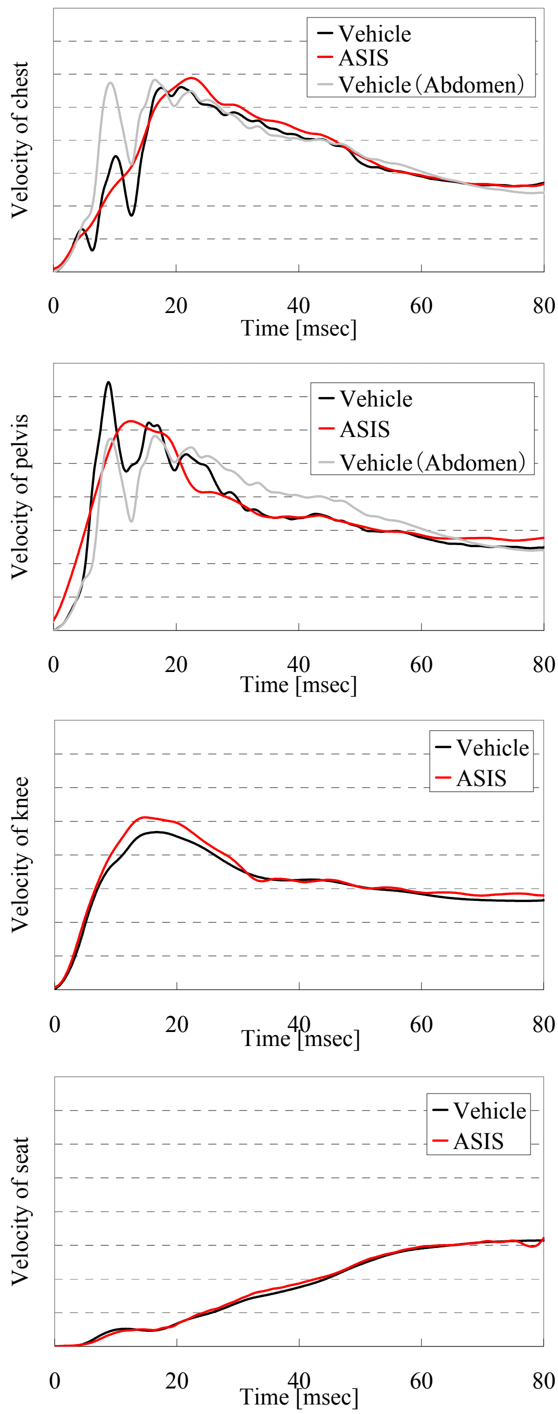


Figure 11. Velocity profiles of door and seat (IIHS).

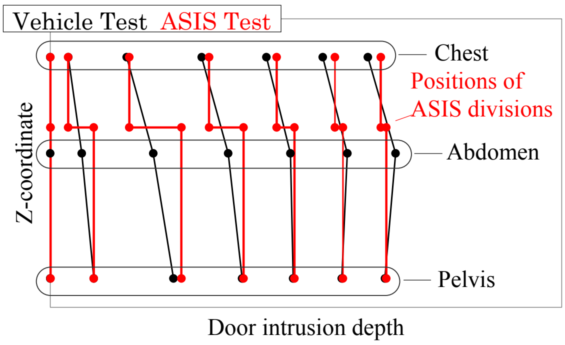


Figure 12. Door deformation in chest, abdomen and pelvis regions (IIHS).

Figure 13 compares the dummy responses in the vehicle test and the ASIS test. The ASIS test data are shown as a percentage of the vehicle test data. The percentage of each rib deflection, acetabulum force, and distal femur moment are all within ±5% of the vehicle test data. The ASIS test data for the distal femur force and the iliac force are approximately 115% and 150% of the corresponding vehicle test data.

Figures 14-20 compare the dummy response profiles in the vehicle test and in the ASIS test. The dummy responses profiles of the ASIS for each rib deflection (Figures 14-15), force (Figure 16) agree well with the corresponding vehicle test profiles. This agreement is attributed to accurate simulation of the door deformation using the multiple actuators, the intrusion of the rapidly accelerating door using the high-output actuators and the input velocity profile using a feedback control function. It is also attributed to accurate simulation of the door deformation needed to reproduce dummy responses.

However, differences are seen for shoulder rib deflection, upper chest rib deflection, acetabulum force, viscous criterion (Figure 17-18) and deflection rate (Figure 19-20). Compared with the other dummy response regions, the ASIS test did not sufficiently reproduce the dummy responses. Two reasons for that can presumably be understood. One reason is number of actuator. Since only three actuators were used to simulate door deformation, just one actuator of chest was used for chest and shoulder regions. As a result, the force input from the door to the upper chest and shoulder rib regions could not be simulated. It was found that in order to reproduce the upper chest and shoulder rib responses, it is necessary to simulate the door deformation more accurately using more actuators. Accordingly, it is necessary to reduce the outer diameter of the actuator. Another reason is low-pass filtering of the input profiles. The difference in the input profiles presumably had a large effect on the viscous criterion and deflection rate. It was explained earlier with regard to the test setup of input profiles that low-pass filtering was done to remove high acceleration components. The filtering process was performed within a range that would not affect the simulation of dummy responses.

It was found that in order to reproduce the viscous criterion and deflection rate, it is necessary to simulate the high acceleration components that cannot be replicated due to the limitations of the ASIS equipment. Accordingly, it is necessary to increase the output of the actuators and reduce the mass of the impactor shown in Figure 7.

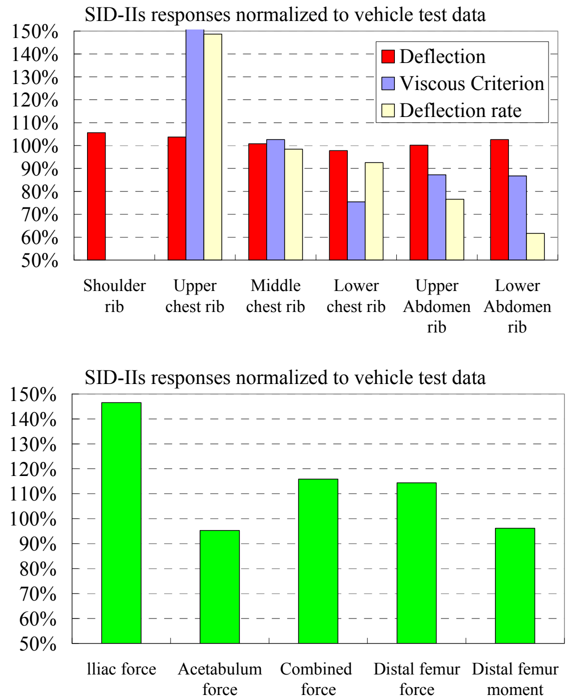


Figure 13. Dummy responses (IIHS).

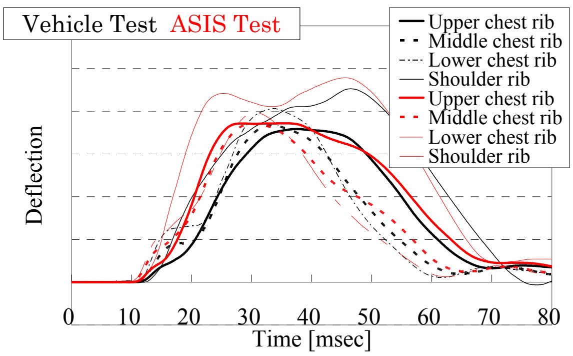


Figure 14. Shoulder and chest rib deflection (IIHS).

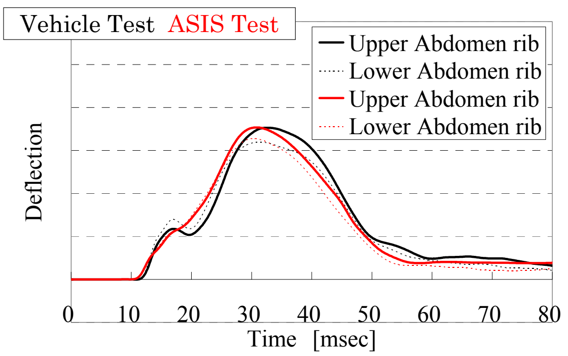


Figure 15. Abdomen rib deflection (IIHS).

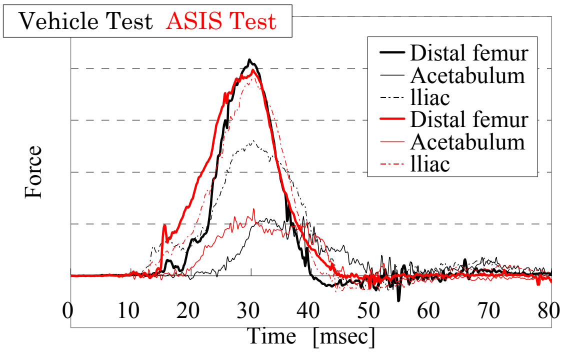


Figure 16. Pelvis force (IIHS).

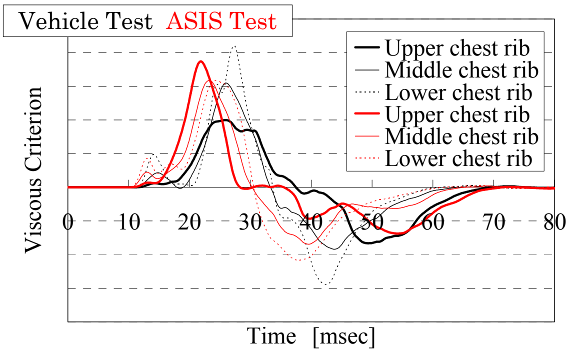


Figure 17. Chest rib viscous criterion (IIHS).

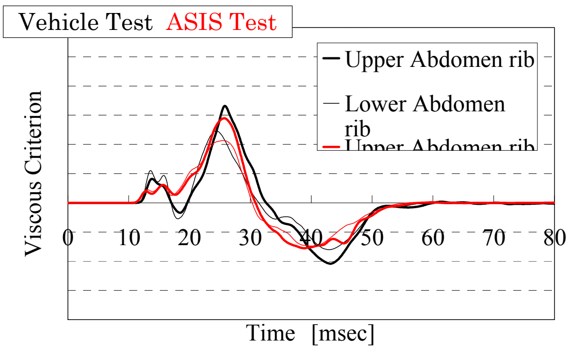


Figure 18. Abdomen rib viscous criterion (IIHS).

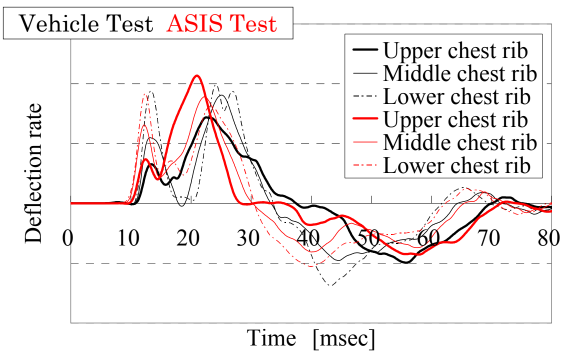


Figure 19. Chest rib deflection rate (IIHS).

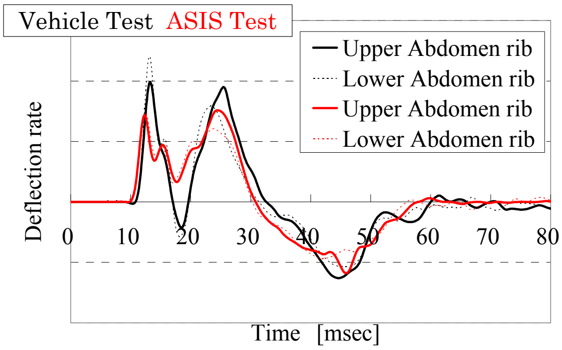
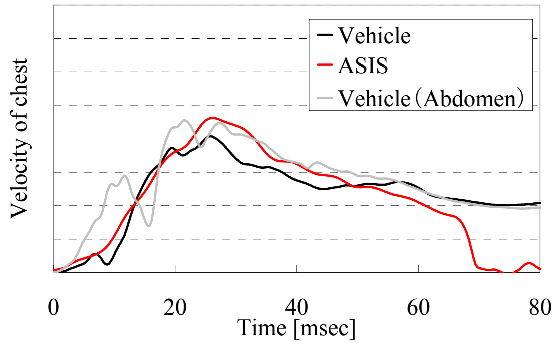


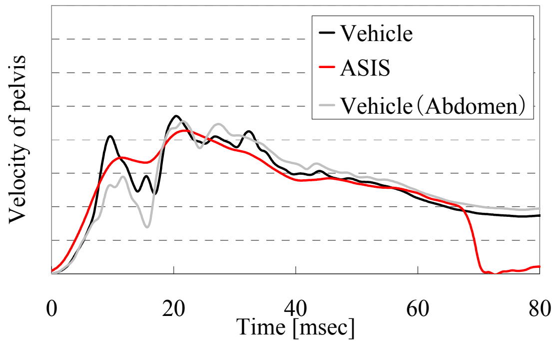
Figure 20. Abdomen rib deflection rate (IIHS).

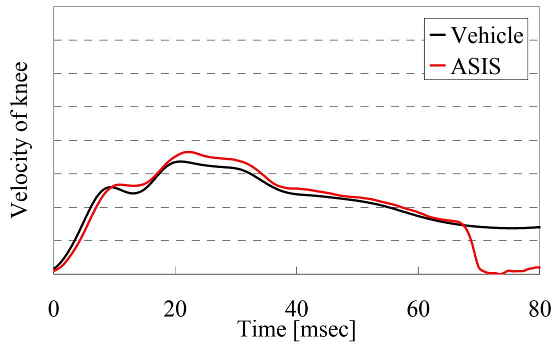
3. EuroNCAP

The vehicle test data and the ASIS test results were then compared with regard to the ES-2 dummy responses under the EuroNCAP configuration.

Figure 21 shows the door velocity profile in the vehicle test and the velocity profiles input into the ASIS actuators. Figure 22 compares the door deformation of the chest, abdomen and pelvis regions between the vehicle test and ASIS test.







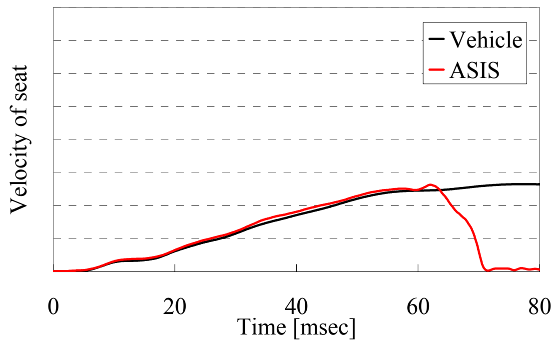


Figure 21. Velocity profiles of door and seat (EuroNCAP).

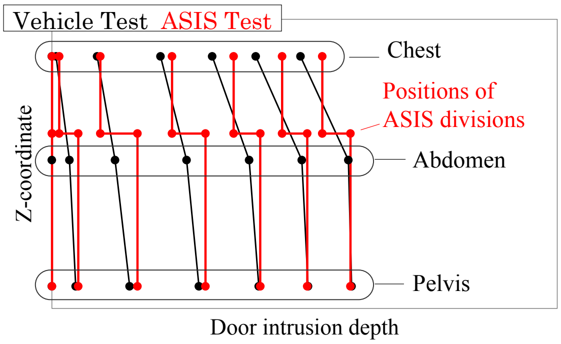


Figure 22. Door deformation in chest, abdomen and pelvis regions (EuroNCAP).

Figure 23 compares the dummy responses in the vehicle test and ASIS test. The ASIS test data are shown as a percentage of the vehicle test data. The ASIS test data of the lower rib viscous criterion is approximately 150% of the vehicle test data. The other dummy responses of ASIS are all within ±10% of the vehicle test data.

Figures 24-27 compare the dummy response profiles in the vehicle test and in the ASIS test. Similar to the results seen for the SID-IIs dummy, the ASIS results for deflection (Figure 24) and force (Figures 26-27) reproduce the vehicle test data well. On the other hand, differences are seen in the viscous criterion profiles (Figure 25). The ASIS results do not reproduce the vehicle test data with sufficient accuracy. Similar to the case for the SID-IIs dummy, two factors seem necessary. One is simulation of the door deformation more accurately using more actuators by reducing the outer diameter of the actuator. Another is less filtering of the input data by increasing the output of the actuators and reducing the mass of the impactor shown in Figure 7.

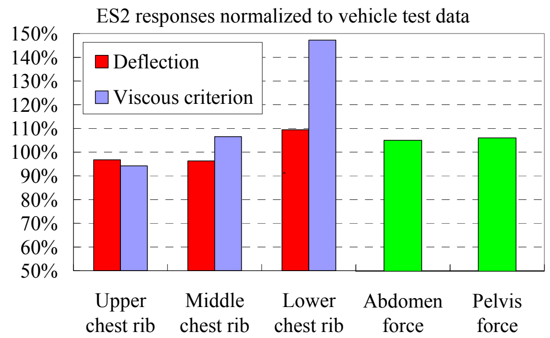


Figure 23. Dummy responses (EuroNCAP).

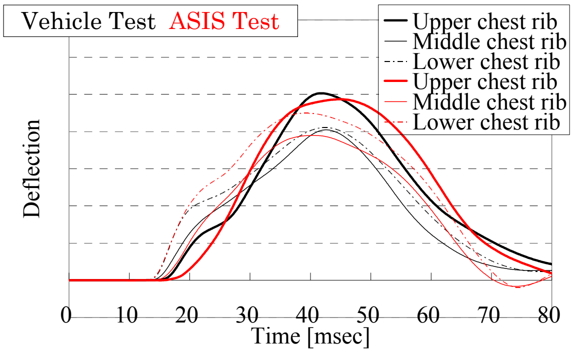


Figure 24. Chest deflection (EuroNCAP).

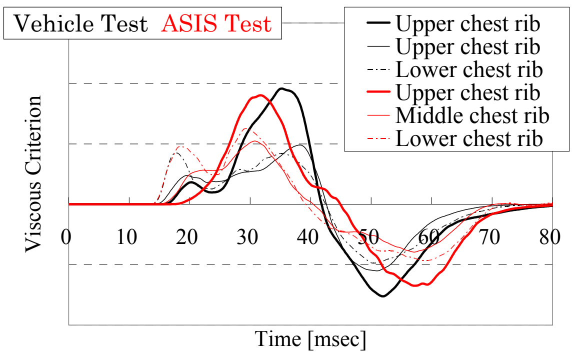


Figure 25. Viscous criterion (EuroNCAP).

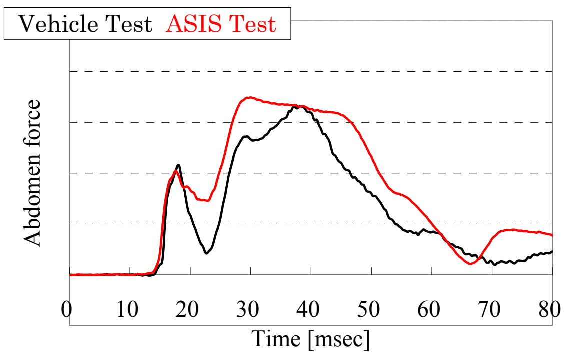


Figure 26. Abdomen force (EuroNCAP).

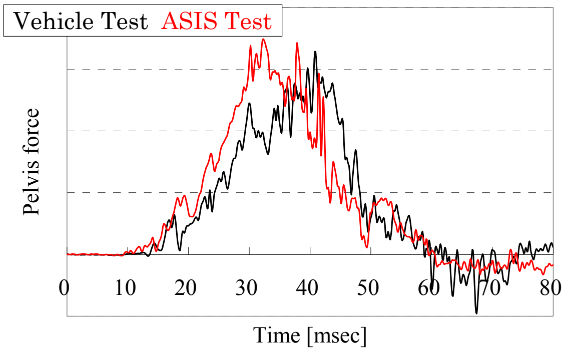


Figure 27. Pelvis force (EuroNCAP).

CONCLUSION

This paper describes a new test method for predicting each dummy response. This method, called the ASIS, has following features to simulate the door deformation behavior needed to predict each dummy response.

- Multiple actuators were used to simulate door deformation behavior.
- High-output actuators were used to simulate the intrusion of the rapidly accelerating door.
- A feedback control function was used to regulate the door and seat velocities of the actuators.

The position of door division is essential in using multiple actuators and was determined for two factors. One factor is door deformation at the positions of each dummy region. Another factor is relative position of the MDB to the door.

The ASIS test data obtained with the SID-IIs dummy for each deflection, acetabulum force and the distal femur moment agreed well with the vehicle test data and were within ±5% of the latter. The ASIS test data obtained with the ES-2 dummy for chest deflection, abdomen force and pelvis force also agreed well with the vehicle test data and were within ±10% of the latter.

However, the viscous criterion and deflection rate have to be further improved. For this improvement, two factors seem necessary. One is simulation of the door deformation more accurately using more actuators by reducing the outer diameter of the actuator. Another is simulation of high door acceleration by increasing the output of the actuators and reducing the mass of the impactor.

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