Study on the Relationship between Intrusion Velocity and Occupant Injury of Side Impact

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Abstract:

Background: The injury outcomes in side impact are correlated to the door trim design, vehicle motion, as well as the side restraint system. A well controlled side intrusion can vastly reduce the injury index of the thorax, abdomen during the side impact. For the safety issue, it is essential to know the sensitivity of side structure's intrusion velocity upon occupant injury in side impact.

Objective: This paper is focusing on the influences of different side intrusion velocities upon occupant injuries, based on a validated MADYMO side impact simulation model.

Method: With the Prescribed Structure Motion method, the side impact occupant model was built up and correlated with the physical impact test to ensure the accuracy of the model. Through the method of Prescribed Structure Motion Scaling, the different door's intrusion velocities corresponding to the chest region were realized. Upon the MADYMO simulations, the side structure intrusion velocity effects on occupant injuries were evaluated.

Results: This study indicates that the door's intrusion velocity corresponding to the chest region has significant effects on the rib deformation and T12-Mx index. By increasing the intrusion velocity from 5.87m/s to 7.5m/s, the maximum of low rib deformation could be increased by 58.6% and T12-Mx index could be increased by 78.4%.

Keywords: Side impact, Intrusion velocity, Occupant injury, MADYMO simulation, Prescribed Structure Motion

1 Introduction

The traffic accident statistics show that the vehicle side impact accident accounted for approximately 40% of the total number of accidents in 2013, and the occupant injury and mortality probability in such accident was as high as 25%, thus side impact is a main accident type for occupant injury and fatalities[1]. Therefore, the research on the safety of side impact has become one of the contents for the passive safety research. The injury outcomes in side impact are correlated to the door trim design, vehicle motion and the side restraint system[2]. A well controlled side intrusion can vastly reduce the injury index of the thorax, abdomen during the side impact. For the safety issue, it is essential to know the sensitivity of side structure's intrusion velocity upon occupant injury in side impact.

This study is focusing on the influences of different side instruction velocities upon occupant injuries, based on a validated C-NCAP[3] side impact simulations model, which is equipped with a side airbag.

2 Method

In this study, both CAE simulation and scaling methods have been used for the side impact simulation and evaluation. Firstly, with the Prescribed Structure Motion (PSM) method, the side impact model was built up and correlated with the side impact test to ensure the accuracy.

Secondly, through the method of Prescribed Structure Motion Scaling, the different door's instruction velocities corresponding to the chest region were realized. The MADYMO model was used to identify the side structure intrusion velocity effects on occupant injuries.

3 CAE model correlation

Based on the vehicle's CAE model, this study applies the method of substructure model to build side impact model, this substructure model is a kind of the modeling technology used to rebuild the intrusion process of the door by the MADYMO software[4]. This technology adopts the Prescribed Structure Motion method to impose the motion of the side and define the MOTION.STRUCT_DISP in MADYMO circumstance. Substructure model's motion is described by the node displacement of the components, in this study the node motion of the door and B-pillar form vehicle crashworthiness simulation was introduced for the occupant kinematics simulation[5]. The deformation of door inner panel from the side impact crashworthiness simulation result is shown in Fig 1, as follows.

Figure 1. Deformation of door inner panel **Figure 2. The occupant simulation model**

Based on the above substructure model, the occupant simulation model was built by importing the ES-2 dummy from the MADYMO dummy database, FE seat model, seatbelt and a correlated side airbag. The position adjustment for each substructure according to physical vehicle test and the contact definition between the each part were carried out afterwards. In this occupant simulation model, the main sub-systems adopt FE-FE contact type. The integrated side impact occupant model is shown in Fig 2 above.

The model validation work was mainly about the dummy positioning and FE-FE contact characteristic definition[6]. The simulation result indicates that the pelvis acceleration of virtual model correlates well with that of physical impact test, see Fig3 below.

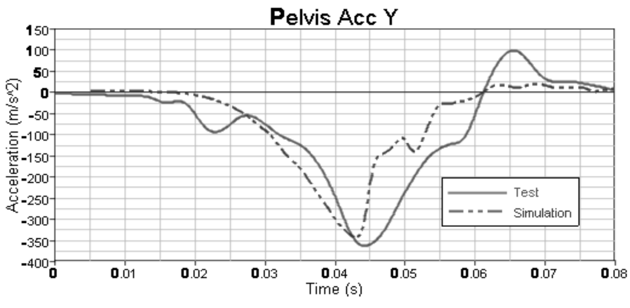

Figure 3. Pelvis acceleration correlation result

The vehicle crash test result indicates that maximum rid compression occurs at the low rib region. Although the raising point of low rib compression from the simulation model is a little late than that of the physical test, both the peak value and trajectory correlate well with those of the test, see the Fig4.

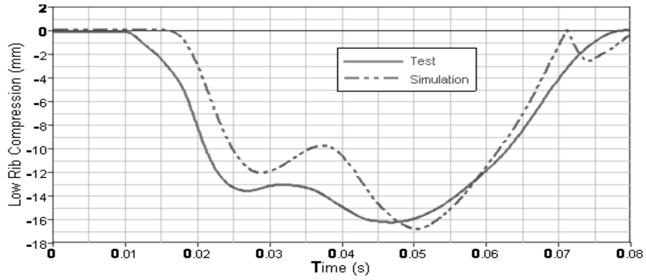

Figure 4. Low rib compression correlation

Figure5 shows the comparison of occupant kinematics and airbag deployment in both test and simulation, which ensures the accuracy of the simulation model as well.

Figure 5. Occupant kinematics and airbag deployment in both test (left) and simulation (right) at 30ms

4 Sensitivity analysis

This study aims to analyze the sensitivity of the dummy injury index to the intrusion velocity, which needs to get the different structure intrusions as the boundary conditions to apply to the correlated model for further analysis. This paper adopts the method of Prescribed Structure Motion Scaling to obtain the required different side sub-structure motion data. The different side intrusion data was used as input for the simulations. By taking a derivative of the side intrusion, we can get the intrusion velocity as well. The initial maximum intrusion velocity at the B-pillar sensor location for the above simulation model is 5.87m/s, which fits well with the sensor records of the physical test. The different intrusion speed velocity by using the Prescribed Structure Motion Scaling method were shown in the Fig6 below.

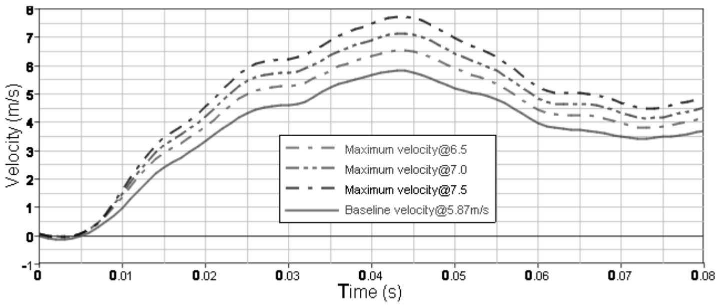

Figure 6. Different intrusion speeds after Prescribed Structure Motion Scaling

In the side impact, the main regions which may suffers severe damage are the chest, abdomen and pelvis regions[7].

This paper only selects occupant chest injury index as the main injury index because the test results indicate other injury index still have margin, and the different intrusion speeds, as shown in Fig6 above, were used as the input for the following sensitivity analysis. The injury index of chest region from the simulations was shown in Fig 7, caused by the different intrusion speeds. After increasing the side intrusion velocity, there is large change for the low rib deformation and T12-Mx index.

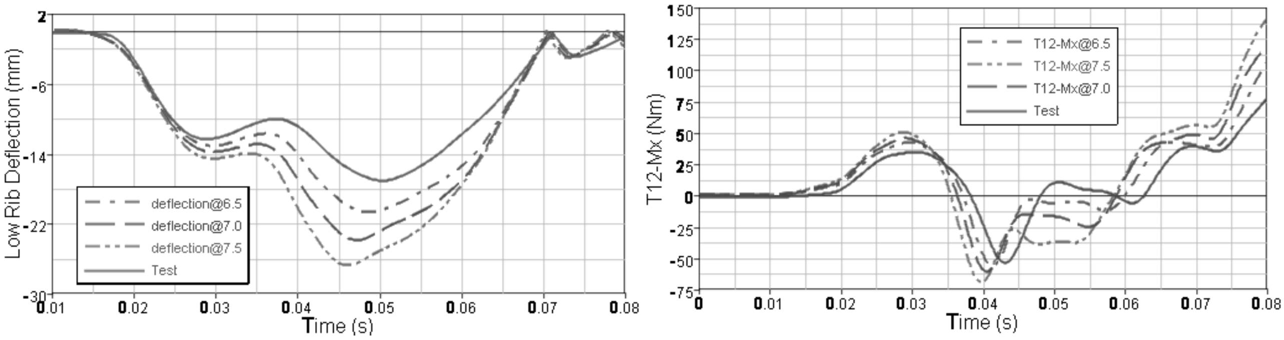

Figure 7. Comparison of low rib deflection (left) and T12-Mx index (right)

By increasing the door's intrusion velocity from 5.87m/s to 7.5m/s, the maximum of low rib deformation could be increased by 58.6%, T12-Mx index could be increased by 78.4% and the VC could be increased by 178%, the injury index under different intrusion load-cases are shown in Table 1.

Table 1. Injury index comparison

The maximum intrusion speed (m/s)	Low rib deflection (mm)	T12-Mx (Nm)	VC （m/s）
5.87	16.9	79.51	0.09
6.5	20.7	107.78	0.14
7.0	23.9	119.71	0.19
7.5	26.8	141.82	0.25

5 Conclusions and discussions

In this study, a MADYMO occupant simulation model for the C-NCAP side impact was built-up and correlated with the physical test, for the purpose of analyzing the sensitivity of side structure's intrusion velocity upon occupant injury in side impact. According to analysis results above, the following conclusions can be drawn:

1: Side impact occupant simulation model with Prescribed Structure Motion Scaling method is efficient to analyze the different side structure crashworthiness results upon the occupant injuries.

2: The side intrusion velocity corresponding to the chest region has significant effects on the rib deformation and T12-Mx index. By increasing the side's instruction velocity from 5.87m/s to 7.5m/s, the maximum of low rib deformation could be increased by 58.6% and T12-Mx index could be increased by 78.4%.

However, for further validation of the research results, a physical side sled test with the maximum intrusion speed at 7.5m/s is highly recommended. Besides, further study will be carried out on effects of the initial space and side airbag stiffness.

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