Evaluation of the Child Restraint System (CRS) Dynamic Performance by Test and CAE Analysis

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Abstract: The main object was to investigate the Hybrid III 3-year-old dummy performance using CAE model due to the variation of different design parameters. A CRS CAE model with 3-year-old dummy was built in MADYMO environment and correlated with the frontal sled test in accordance with ECE-R44 regulation. The correlation work was mainly concentrating on occupant kinematics and chest accelerations. Based on the validated model, influence of certain design parameters (including belt elongation, buckle position etc.) on dummy kinematics and injury index was studied. This study is beneficial for the future research on CRS design and performance evaluation.

Keywords: child restraint system; simulation; test; evaluation; MADYMO

1. Introduction

In 2006, 4167 children under 12 died in the accidents in China, which including 683 child occupants. The main cause for the deaths of the child occupants was the incorrect sitting posture, such as misuse of the child restraints systems[1]. Currently, the supplemental restraint systems in the vehicle are mainly designed for the adults which may result in serious injuries for children in a crash. A poorly positioned vehicle seat belt may lead to rapid, "jack-knife" and/or “submarining” effect, which increases the risk of intra-abdominal and spinal cord injuries[2]. Accident data have demonstrated that a Child Restraint System (CRS) is effective for preventing injuries to children[3].

Figure 1. CRS set-up in C-NCAP full front impact test

The first mandatory national standard on “Vehicle Child Occupant Restraint System” will be put in force in early 2011 in China. In addition, China New Car Assessment Program (C-NCAP) crash tests have been revised, and include the evaluation of CRS performance in the full frontal crash test since 2010, see Figure1. Thus, it is urgent to carry out the study on the Child Restraint System.

Currently, the evaluation of CRS performance is mainly based on the sled test and CAE analysis. The CRS prototype development and existing design optimization are carried out almost exclusively via the sled tests. The CAE methodology can help identify the main parameters of the design and answer the “What-if” questions in virtual environment. The objective of this study was to validate the CRS CAE model and to examine the CRS performance by changing certain design parameters.

2. Method

In this study, a certain CAE CRS model was developed and validated against the sled test. Based on the validated model, certain design parameters’ influence on dummy injury metrics (HIC, and chest accelerations) was evaluated, by introducing the Design of Experiment (DOE) methodology. Finally, the conclusion was drawn.

2.1. CRS Performance by Sled Test

The dynamic test of the VRS was performed on an impact sled located in China Automotive Technology and Research Centre (CATARC). The purpose of the sled test was to identify the kinematics of P3 dummy and the CRS during the sled test, and output the data and video required for the following analysis and CAE model correlation. This test was arranged according to the ECE-R44 regulation, see Figure2.

Figure 2. The CRS forward-facing sled test

The sled test was carried out on the inverse crash facility in CATARC，with the initial velocity of 0km/h. A TNO P3 dummy was set on the CRS to examine the dummy kinematics and injury index. This child restraint system had no ISOFIX device, see figure above. The motion of the CRS and dummy was captured by the high speed camera (1frame/ms).The pulse of the sled test is shown in Figure3.

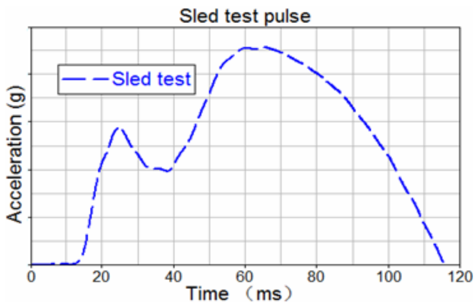


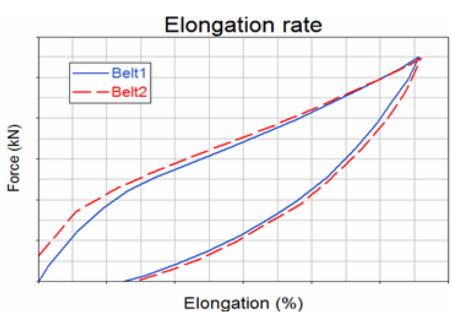
Figure 3. Sled test pulse

2.2. Component Tests

For the MADYMO simulation, the force-deflection of each component is required as simulation input. The components required for tests included child belts, adult belts, and the seat base of the CRS. All of these tests were carried out within the material machine, as shown in Figure4.

Figure 4. Compression test of the child seat

Both the child belts of the CRS and the adult belts of the vehicle were test in this research, and the belt elongation test results are shown in Figure5:



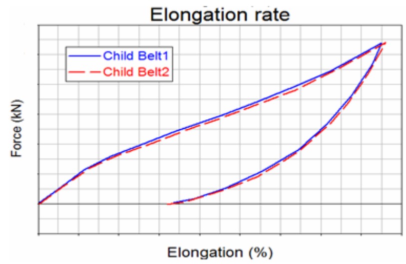


Figure 5. Elongation rates of the adult belts (up) and child belts (down)

2.3. CRS Modeling

The modeling work included the bench seat modeling and the CRS development. The bench model was modeled with finite elements, to simulate the deformation and its effect on the child seat kinematics. The child seat was model with shell finite elements which represents the geometry well. The belt model contained multi-body belt and Finite Element (FE) belt which had certain accuracy and was efficient in computation. The TNO-P3 dummy model from the MADYMO database was imported in the environment, the position of the dummy was set up according to the test. The whole model was developed, as shown in Figure6.

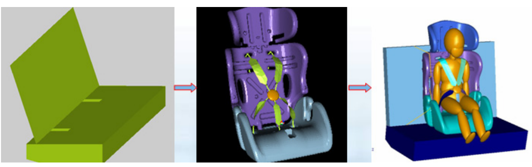
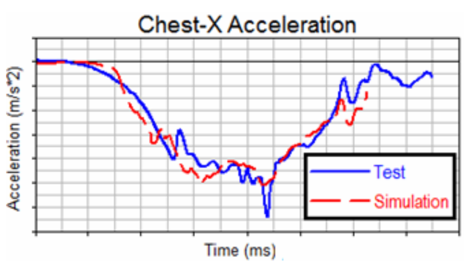


Figure 6. Modeling of the CRS system

2.4. Model Correlation

The kinematics and injury index were exported from the simulation. Figure7-left shows the chest-X accelerations of test and simulation, while Figure7-Right shows the chest-Z accelerations of test and simulation. The simulation results correlated well with those of the test.

Also, the kinematics of the simulation was exported, for the comparison with that of the test. The animations of the MADYMO simulation at time 0ms, 50ms, 80ms were compared with those of the test at the same time. The P3 dummy kinematics matched well with that of the test, see Figure 8.



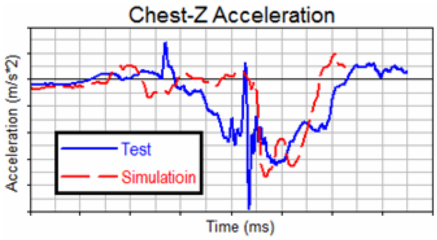


Figure 7. Correlations of Chest-X (up) and Chest-Z (down) accelerations

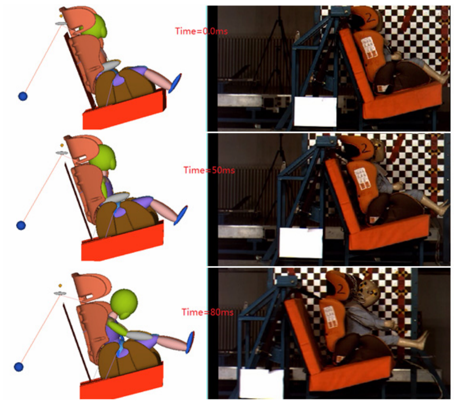


Figure 8. Kinematics comparisons of test and simulation at 0ms, 50ms, 80ms

From the comparison above, it was concluded that the MADYMO model correlated well with the sled test. This MADYMO model can be used for further parameter study.

2.5 Parameter Study

Parametric studies were conducted on the validated model with the 3-year-old child model as the baseline model. Parameters including dummy-seat contact friction, belt holder position, buckle position, and child belt elongation were taken into analysis. The injury evaluation was mainly based on the criteria proposed by David C.Viano [4], see equation1. Four parameters and their ranges taken into the DOE simulation are shown in the following Figure 9.

$$I=0.7*(HIC36/1000)+0.3*(C3MS/60) \quad (1)$$

Where HIC36 is 36ms Head Injury Criterion, C3MS is 3ms Chest acceleration (g).

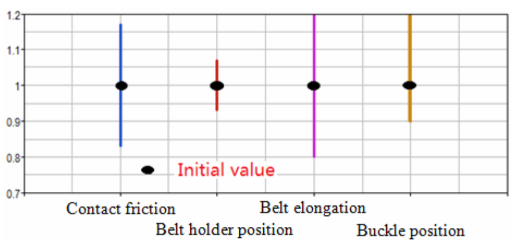


Figure 9. Parameters and their ranges taken into the parameter study

3. Results

Considering the parameters mentioned above, the DOE methodology was used to set up the simulation matrix and evaluate the effect of different parameters, see table1. The simulation results are shown in the Table1 as well.

The simulation results above indicate the current CRS design is efficient in the protection of head and chest areas. It is also shown that increasing the contact friction between dummy and child seat can reduce the HIC and chest acceleration slightly, when considering these limited parameters. In this study, the peak head acceleration was reduced, when the friction force increased.

4. Conclusions

1) It is shown that sled test, combined with the CAE provides an efficient way to study the CRS kinematics and occupant injury index.

2) Simulation results above indicate it is better to keep current parameters, and increase the contact friction between dummy and child seat for the head and chest area protection.

3) This study also showed that it was beneficial to use the DOE methodology to reduce the number of simulation cases, and identify the main design parameter.

4) It is advised that more dummy parameters, such as head acceleration and excursion, should be taken into consideration for more detailed analysis.

Table 1. DOE matrix and the simulation results

	DOE set-up				Simulation results		
Test	Fric	Holder- Pos	Elongation	Buckle -Pos	HIC	C3 (g)	I
Test1	0.3	0.4	80%	0.15	313.3	265.3	0.355
Test2	0.3	0.43	100%	0.16	289.3	267.9	0.339
Test3	0.3	0.46	120%	0.18	311.4	271.8	0.357
Test4	0.35	0.4	80%	0.15	296.1	263.9	0.342
Test5*	0.35	0.43	100%	0.16	281.4	263.9	0.332
Test6	0.35	0.46	120%	0.18	300.3	271.0	0.348
Test7	0.4	0.4	80%	0.15	291.6	262.0	0.338
Test8*	0.4	0.43	100%	0.16	273.4	263.4	0.326
Test9	0.4	0.46	120%	0.18	285.9	269.6	0.338

*Note: Test5 is the original one and Test8 is the optimized one

Acknowledgement

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