Evaluation of Anchorage Systems of Child Restraint According to ECE R44 by Computer Simulations

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Abstract: The anchorage system of child seat has a strong effect on the protection efficiency of the seat itself. Currently, there are three main methods to attach child restraints to the vehicle structure: using adult safety belt, LATCH and ISOFIX. In order to compare the dynamic responses of children and injury related parameters when various anchorage systems are used, the authors evaluated three systems: adult safety belt, LATCH, ISOFIX and all systems were simulated with/without top tether. We used MADYMO software and simulation models in accordance to the frontal impact sled test prescribed in ECE R44/04 regulation. The result confirmed that seats using rigid ISOFIX anchorages generally produced lower head acceleration and forward head excursion than other anchorage types but did not decrease the injury risk of the thorax and neck clearly. The injury risk for the case of seats using LATCH without top tether is highest. Seats using LATCH and adults seatbelt with top tether had similar protection effect on children. The top tether could reduce children's head forward displacement, head and thorax acceleration.

Keywords: anchorage system; seatbelt; LATCH; ISOFIX; injury analysis

1. Introduction

For the first time China, of which automobile production and sales in 2009 were more than 13.5 million, became the largest vehicle consumer market instead of USA. However, the rapid growth of automobiles does not raise people's awareness of child safety. According to the data from Ministry of Traffic Police, in 2008 in the traffic accidents of our country, there are 2,116 deaths and 6,350 injuries involving children from 1 to 6 years old, account for 2.88% and 2.08% of all the casualties [1]. The number of deaths and injuries can be strongly reduced by use of restraint systems. The statistics of NHTSA demonstrate that the use of children restraint system can reduce the fatality rate of children in traffic accidents by 71% for infants and by 54% for toddlers [2].

Child seats can provide appropriate protection if they are properly installed in the vehicle. Currently, there are three main anchorage systems; one is to restraint the child seats using adult seat belts. This system causes a lot of trouble during the installation process. According to one investigation data from USA, at least 67% of cases the child seat was not been properly mounted by seatbelts and resulting in increase of the injury risk. The second system ISOFIX was developed in 1999 in Europe by International Standards Organization. The third system LATCH (Lower Anchors and Tethers for Children) was proposed by regulation in 2002 in the USA [3]. The difference between the last two systems is that flexible LATCH connects child seat to vehicle seat by strips and has one top tether, when ISOFIX emphasizes the rigid lower anchorages and the top fixture point is not mandatory. The benefit of these two systems is to reduce misuse rate.

Several studies have been done by foreign researchers related to the regulation in their countries. Belcher et al.[4] conducted a series of 28 frontal impact sled tests with varying anchorage configurations including rigid ISOFIX, flexible LATCH strap and 3-point seatbelt based on the Australian Standard AS/NZS 3629. The results suggest that lower anchorage systems may be acceptable in Australia, but that modifications to the UN-ECE and LATCH requirements may be required to ensure compatibility with existing Australian child restraint systems without a degradation of child safety. Chand Manikonda[5] from USA investigated the occupant response of HybridIII 3 dummy restrained with flexible LATCH and ISOFIX systems positioned in FFU configuration according to FMVSS213 by MADYMO simulations. His results demonstrated that both the systems could perform well, under the condition that any adjustment in the attachment system was tightened. The flexible LATCH system was particularly sensitive to misuse. In Japan, Mizuno. et al.[6] conducted the ECE R44 sled test simulations using the child and HybridIII FE models for three different types of CRS such as a 5-point harness, an impact shield and ISOFIX CRS. As a result, in the 5-point harness CRS, the head down movement and its rotation were large for the child human FE model. The head excursion was particularly small for

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the ISOFIX CRS. A slack seatbelt and harness in the 5-point harness CRS increased the injury risk. All of the studies showed the good performance of ISOFIX.

In our country, the child seats usage rate is very low; the cars equipped with ISOFIX/LATCH system are very few. Most of child safety seats are restrained by adult seat belts, and our mandatory standard of child restraint system is considered according to European regulations. Therefore in the current study, based on the ECE R44 sled test, we developed six simulation models in MADYMO for three types of anchorage systems, which were properly used. We mainly compared the dynamic responses of seatbelt and LATCH system, seatbelt and ISOFIX system.

2. Methodology

2.1. Model Development

The simulation model (Figure 1) was developed in accordance to the frontal impact sled test. It included the sled seat model, child seat model, belt models and P3 child dummy model. The cushion and back of the sled seat were represented by planes connected to the inertial space. The model of the child seat was developed by facets and the seat is used to protect children whose age is from 0 to 6 years, so P3 dummy was chosen as the research objective. The harness integrated in the child seat was of hybrid type, and was composed with rigid-body and FE parts. The three-point seat belt system was presented by six belt segments to simulate the shoulder and lap belt.

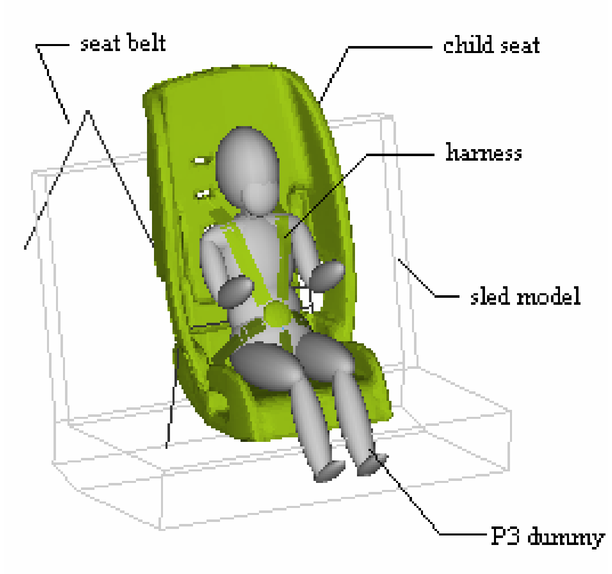


Figure 1. Simulation model

According to the different installation and occurrence of the top tether, six models are investigated as shown in Table 1.

Table 1. Simulation Cases

Case No.	Anchorage system	Top tether
1	Seat belt	without
2	Seat belt	with
3	LATCH	without
4	LATCH	with
5	ISOFIX	without
6	ISOFIX	with

The child seat presented in Figure 1, can not only be fixed using the vehicle seat belts, but also can be used with LATCH/ISOFIX installation system on the car. For the study of kinematics of child dummy protected by CRS using various attachments, the same MADYMO CRS model was used. In the model of LATCH, the LATCH straps and top tether were simulated using belt segment [7]. The distance between the two fix points of the LATCH is set up according to FMVSS 213 [8]. In the model of ISOFIX, two rigid bars have been used. These two rigid bars were designed to the same dimension as depicted in ECE R44 [9] and built by ellipsoids [10]. Fixed effect was achieved by the contact between the rigid bars and the anchorages on the vehicle seat. The simulation models of LATCH and ISOFIX anchorage systems are shown in the Figure 2 and 3.

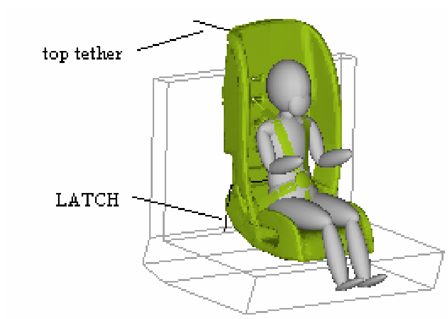


Figure 2. LATCH system

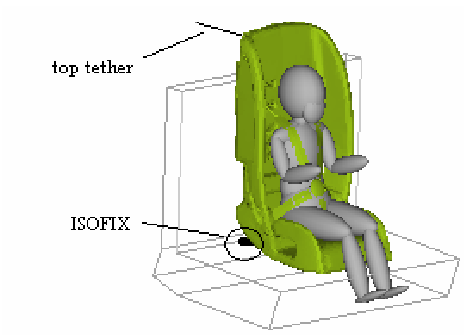


Figure 3. ISOFIX system

2.2. Model Validation

Simulation model validation was completed by comparing the numerical simulation results with the experimental findings from the frontal impact test conducted by National Center of Supervision and Inspection on Motor Vehicle Products Quality [11]. In this test the child seat was attached to the sled by seat belts (Figure 1). We simulated the stationary sled and applied an acceleration field on the child seat and dummy. The acceleration pulse used in the simulation is illustrated in Figure 4. In the validation the resultant head and chest acceleration were compared between the simulation and test.

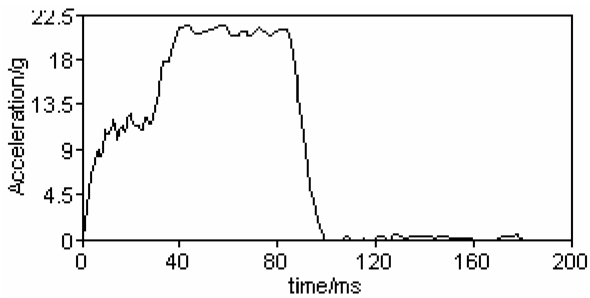


Figure 4. Simulation pulse

The experimental and numerical results are shown in Figure 5 and 6. The numerical model over predicted the head and thorax resultant acceleration from experimental tests by less than 15%, therefore, it was accepted in current study.

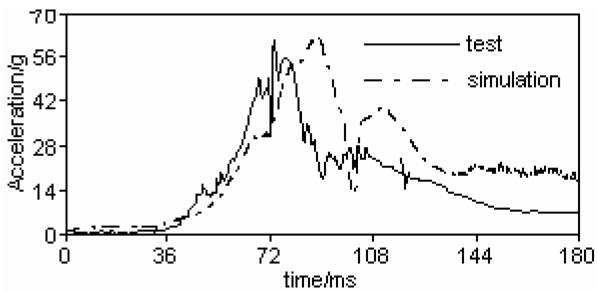


Figure 5. Head resultant acceleration

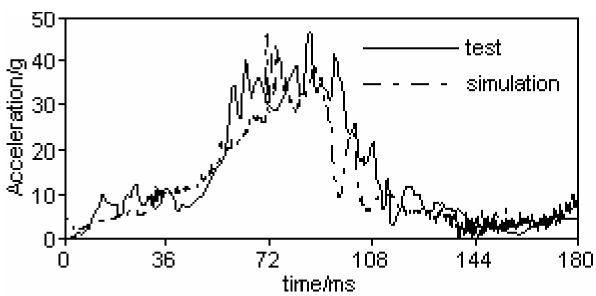


Figure 6. Thorax resultant acceleration

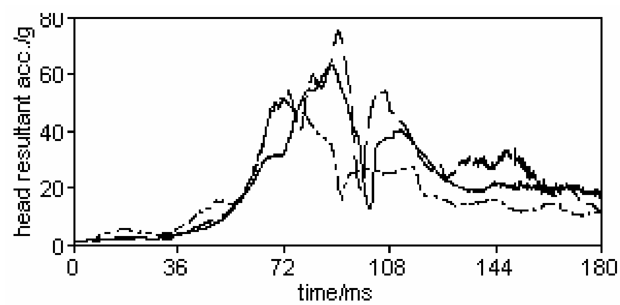
2.3. Selection of Evaluation Parameters

For frontal impact, injury measures are recommended for the head, neck, chest and abdomen. Priority of body segment protection depends on the ECE-R44 group. De Jager K. et al.[12] have indicated that when forward facing systems (Group I) is used for children of three years old , head injury is a big issue, the neck is an import area to protect for children in forward facing CRS, even if these injures are not very frequent. The limits of ECE R44 regulation indicate, the resultant chest acceleration shall not exceed 55 g except during periods whose sum does not exceed 3 ms, the head forward movement of the dummy shall not pass 550 mm.

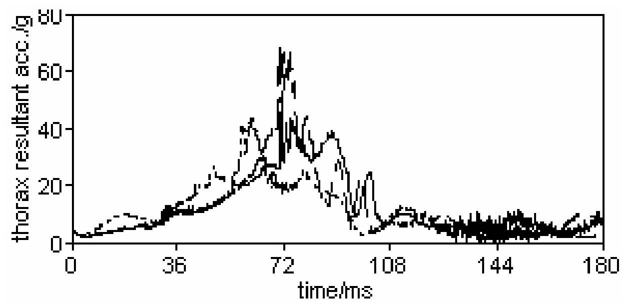
Based on their study and ECE R44 criteria, several parameters of the dummy (head resultant and thorax acceleration, neck flexion moment, neck shear force,3ms head and thorax resultant acceleration, head forward excursion) were chosen for evaluation of the performance of the fixtures.

3. Results and Discussions

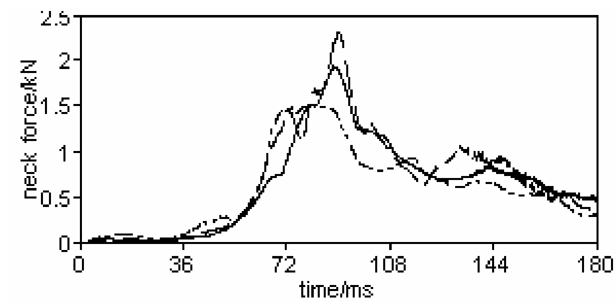
Figure 7 shows injury parameters curves including head resultant acceleration, chest resultant acceleration, neck flexion moment, neck shear force obtained from the simulations of three anchorage systems without top tether.



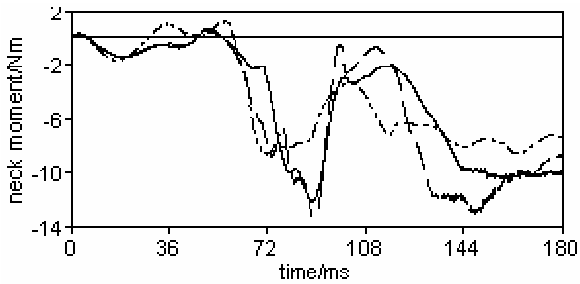
(a) Head resultant acceleration



(b) Thorax resultant acceleration



(c) Neck shear force



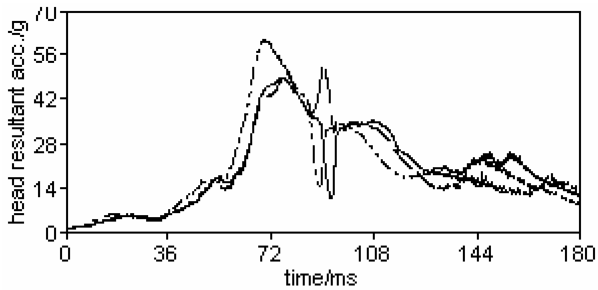
(d) Neck flexion moment

Figure 7. Injury parameters curves obtained from simulations of CRS without top tether (——— Seatbelt without tether — — LATCH without tether –·–·– ISOFIX without tether)

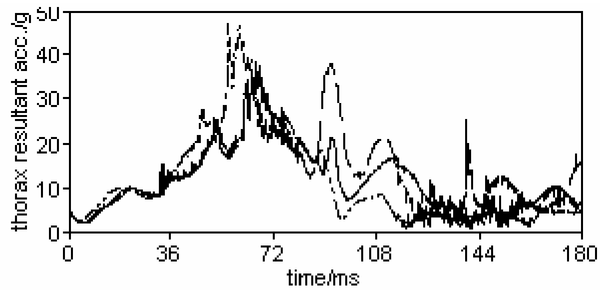
In the case of rigid ISOFIX, the resultant head peak acceleration value is 19% smaller than in the case of seatbelt. The chest peak resultant acceleration values are similar, approximately 44g. The neck force and moment for simulation of rigid ISOFIX are clearly smaller than that from simulation of seatbelt, and the time occurrence of peak value is earlier in case of ISOFIX. Those are because the rigid connections of ISOFIX limit forward motion of the child seat, the harness restrains the chest in advance and children's chin contacts with the chest early. In the cases of flexible LATCH and seatbelt, the shape of the curves and the time occurrence of the peak value are similar. In the case of LATCH fixation every peak value of injury related parameters are higher than in the case of seatbelt, especially peak chest resultant acceleration increased nearly 50%. The main reason is that due to particular rotation of the CRS the restraint force applied to the children by the harness system is more to the chest and less to abdomen.

Figure 8 shows injury parameters curves of three anchorage systems with top tether. In the case of rigid ISOFIX the resultant head and chest peak acceleration values increased with 15 g in relation to the case of seatbelt. The neck force and moment also increased and the time occurrence of peak value is earlier in case of ISOFIX. This is because in the model rigid ISOFIX with top tether made the installation of the seat rigid and the relative velocity between child and seat increased. In the cases of flexible LATCH and seatbelt, all curves' shapes are similar. The only difference is that the peak values of all injury related parameters occur at 90 ms in the case of LATCH, probably because the constraint of LATCH to the child seat at the time of 90 ms caused the increase of the relative velocity between dummy's head and chest, so the harness constraint the dummy more severely than in the case of seat belt.

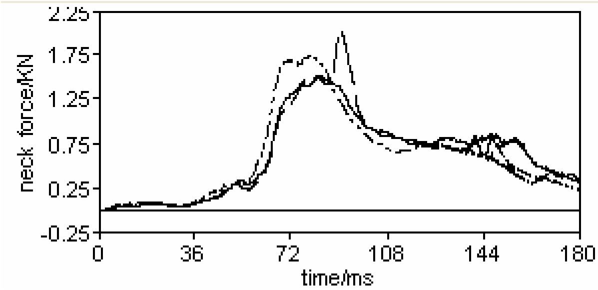
Figure 9 shows the 3 ms resultant acceleration. Based on the analysis of acceleration one can see that the injury risk in the case of seatbelt, the 3 ms resultant head and thorax acceleration values with top tether are lower than those without top tether, the 3 ms head resultant acceleration decreased by 22% and 3 ms thorax resultant ac



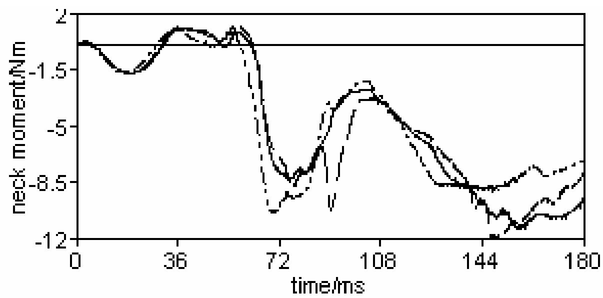
(a) Head resultant acceleration



(b) Thorax resultant acceleration



(c) Neck shear force



(d) Neck flexion moment

Figure 8. Injury parameters curves obtained from simulations of CRS with top tether (——— Seatbelt with tether — — LATCH with tether –·–·– ISOFIX with tether)

celeration decreased by 17%. In the case of flexible LATCH, the 3 ms resultant head and thorax acceleration values with top tether are also lower than those without top tether; the 3 ms head resultant acceleration decreased by 30% and 3 ms thorax resultant acceleration decreased by 33%. In the case of rigid ISOFIX, the 3 ms head and thorax resultant acceleration with top tether are slightly higher than that without top tether, probably because in the model the fixation of ISOFIX with top tether is excessively rigid. The head acceleration is highest for the case of LATCH without top tether, close to 70 g. The 3ms chest resultant acceleration obtained from all six simulations were all below 55 g that is the limit in the ECE 44 regulation.

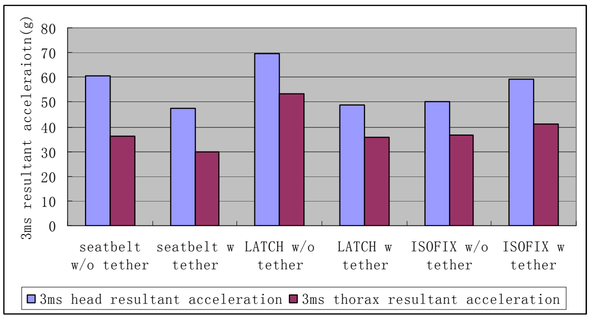


Figure 9. Resultant acceleration(3 ms)

Figure 10 shows dummy forward head movement. In the case of rigid ISOFIX anchorage with top tether the forward head excursion is lowest, approximately 415mm, and in the case of seat belt without top tether this movement is highest, approximately 539 mm. The head movement in cases of anchorage systems with top tether is lower than those without top tether. The forward head movements of all six simulations are below 550 mm that is the limit in the ECE 44 regulation.

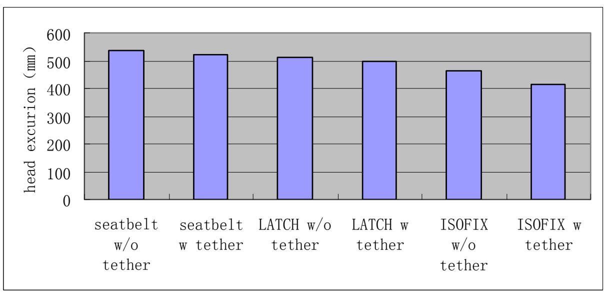


Figure 10. Forward head excursion

4. Conclusions

The application of current three main anchorage systems was simulated and analyzed in the frontal crash configuration. The seats using rigid ISOFIX anchorages generally produced lower head acceleration and forward head movement than other anchorage types but did not decrease the injury risk to the thorax and neck clearly. In the case of seat using LATCH without top tether the injury risk was highest. Seats using LATCH and adults seatbelt with top tether had similar protection effect on children. Compared with the simulations without top tether, the top tether can reduce head forward movement, head and thorax acceleration.

The protection level could be increased by optimization of parameters of straps such as the angle and material. This topic could be considered in further study. Another problem is that the child protection systems are very often misused. We didn't study this question, but it should be of public interest to learn more about risks when various systems are not properly used.

We should pay more attention to child safety, keep up with international advanced regulations, formulate and improve rules of our country for child restraint system as soon as possible.

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