Proceeding of the 14th International Forum of Automotive Traffic Safety, 2017, pp 543-549
No.ATS.2017.517

Analysis of the equation of motion on the chest of Hybrid III 3YO dummy in dynamic loads

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Abstract: To investigate the chest loadings of the 3-year-old child occupant in detail using a child restraint system (CRS), a finite element model of sled and energy absorption tubes were established by LS-DYNA. The Sled-CRS FE model in a frontal impact test simulation was conducted utilizing Hybrid III 3-year-old dummy. A method of reproducing crash pulse with the combination of thin-walled circular tubes was used to satisfy acceleration interval requirements of ECE R44 regulation. The equation of motion of chest was established by the internal forces (lower neck, shoulder joint, upper lumbar spine) and external forces (seatbelt force) that are exert on the chest. The simulation results showed that the chest acceleration is related to the external and internal forces. Based on this formula, the mechanism of the chest acceleration that was generated can be examined with time. According to the forces that applied the dummy chest, it is possible to known the load applied to the chest and to judge whether the forces is balanced.

Keywords: Hybrid III 3YO; Sled model; Frontal impact; Equation of motion of chest

1 Introduction

Motor vehicle crashes are the most significant factor causing child fatalities. Research on the effectiveness of child restraint systems (CRS) has found them to reduce the risk of fatal injury by 71% for infants and by 54% for toddlers in passenger car [1]. Accident data have demonstrated that a child restraint system is effective for preventing injuries to children [2].There are a variety of forward-facing CRS types, such as the 5-point harness, impact shield and booster. As an ISOFIX CRS is anchored in the vehicle seat by two rigid anchorages, it can be attached to the vehicle seat rigidly. To limit the pitch motion of the ISOFIX CRS, some anti-rotational devices are required. For a forward-facing ISOFIX CRS, such as supporting leg as an additional installation measure.

Statistical data of motor vehicle related accidents showed that the most frequently injured body part for children in frontal or side crashes is the head [3]. However, as the child thoracic is very soft, the organs and tissues inside the thorax are still not fully developed, the thorax cannot play a fully protective for the liver and spleen [4]. In the frontal impact crash, when the child's chest is subjected to excessive compression by the tightening of the seat belt, the organs of the thorax are vulnerable to damage under pressure and shear forces [5]. Moreover, since a small child has a large head and a fragile neck structure, the loadings to the neck probably may cause a severe or fatal injury, which has been revealed in real-world accidents [6]. Jager[7] et al. also have indicated that the neck is an important area to protect for children (younger than 4year of age) in forward–facing CRS, even though these injuries do not occur very frequently. Hu [8] et al. analysed the kinematic behaviour and responses of Hybrid III 3YO dummy and child human FE model in ISOFIX CRS in frontal impact. Chest acceleration was initially studied as one of the criteria for chest injury. And the chest resultant acceleration measured at thoracic spine was the criterion of the chest. Because the restraint device, the neck, the lumbar spine and the shoulder joint can transmit force to the thoracic spine, the proportion of these forces can be studied by chest acceleration [9].

In this research, the method of reproducing the sled acceleration in regulation corridor was conducted and the sled-CRS FE model was established by LS-DYNA. For evaluating the loadings on the chest, the kinematic behaviour and injury measures was analyzed by using the Hybrid III 3YO FE model, and the equation of motion was established based on chest acceleration.

2 Method and material

2.1 Sled model

To satisfy the acceleration interval requirements of dynamic frontal crash test in UN R44 regulations, a finite element model of sled and energy absorption tube were established by LS-DYNA. Figure1 show the sled FE model in frontal impact. The sled FE model mainly consists of trolley and ECE test seat. The sled is 2620 millimeters in length and 1070 millimeters in width. The material of sled is Q235.The material of ECE seat cushion is foam, which was realized with solid elements. The thin-walled circular energy absorption tubes were constrained in specified circular sleeves that is molded by hexahedron. The material of energy absorption tube and sleeve are aluminum and mat20 respectively. The total element number of sled model is 89395, the number of nodes is 90656.The weight of sled model can be adjusted by mass point.

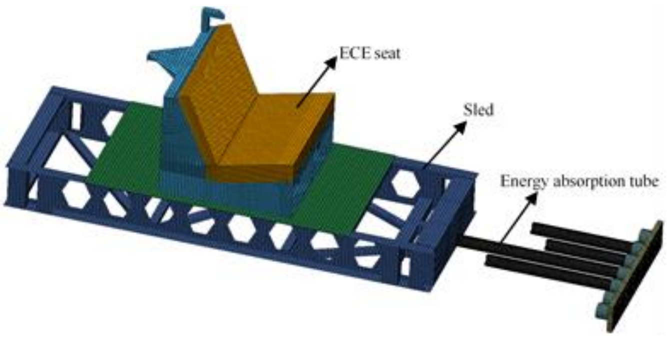

Fig .1. Sled FE model

2.2 FE model for CRS

Figure2 is the 5-point harness ISOFIX CRS FE model. The CRS FE model mainly consists of skeleton and seat base with two point ISOFIX attachments. ISOFIX and 5-point harness for the constraint way of CRS, besides, a supporting leg of assistive device was provided more rigid support for the restraint. The most parts of the seat were modeled by shell elements and the element size is 8 millimeters. The harness was molded by membrane and seatbelt elements. The main material of the seat is polypropylene. The figure 3 is the true stress and strain curve of polypropylene material. The strength components of ISOFIX and supporting leg are Q235.The total mass of CRS is 11.42 kilograms. The total number of elements and nodes are 40458 and 41421 respectively.

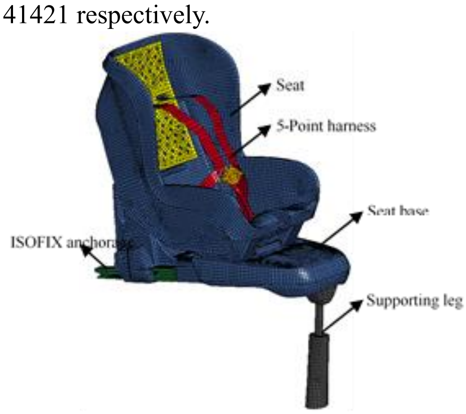

Fig .2. ISOFIX CRS FE model

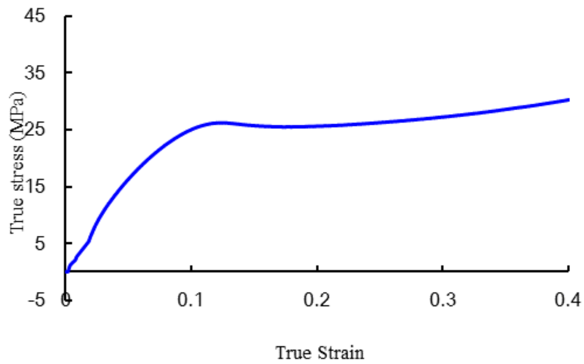

Fig .3. Ture stress-strain curve of PP

2.3 Sled-CRS FE model in frontal impact

The figure 4 shows the Sled-CRS FE model in frontal impact based on the ECE R44. The CRS FE model was set in place on the ECE seat according to the ECE R44. The sled test was conducted using the Q3 for the 5-point harness. Then in the present study, the CRS sled test was simulated by the Hybrid III 3YO FE model for basic research. To simulate a frontal crash with sled model at an initial velocity of 50km/h. The acceleration curve of sled was reproduced by different numbers, lengths, and thicknesses, diameters of the energy absorption tubes and different weight of the sled device.

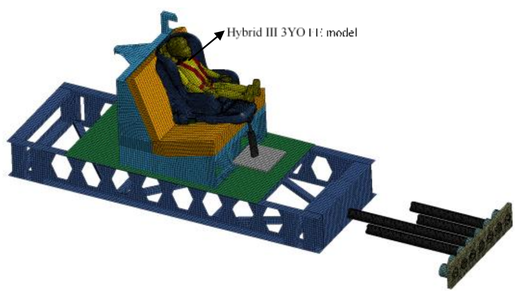

Fig .4. Sled-CRS FE model in frontal impact

3 Results

3.1 The acceleration of sled

When the trolley is adjusted to the quality of 710kg, it can be fitted to meet the frontal impact acceleration interval requirements of the ECE R44. The parameters of energy absorption tubes are shown in Table1. The combination and number of energy absorption tubes were shown in figure5.

Table 1. The parameters of energy absorption tubes

Absorption tube number	2	3	4	5
length/mm	700	570	1080	850
thickness/mm	2	2	1.2	2
diameter/mm	75.5	75.5	75.5	75.5

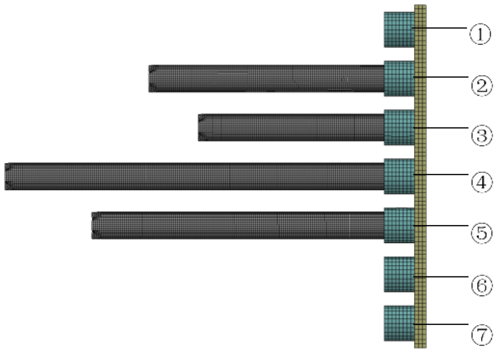

Fig .5. The combination and number of energy absorption tubes

Figure 6 shows the sled acceleration pulse in frontal impact. It suggested that the simulation wave is almost falls within the regulation acceleration channel except a tiny part at the end of the curve.

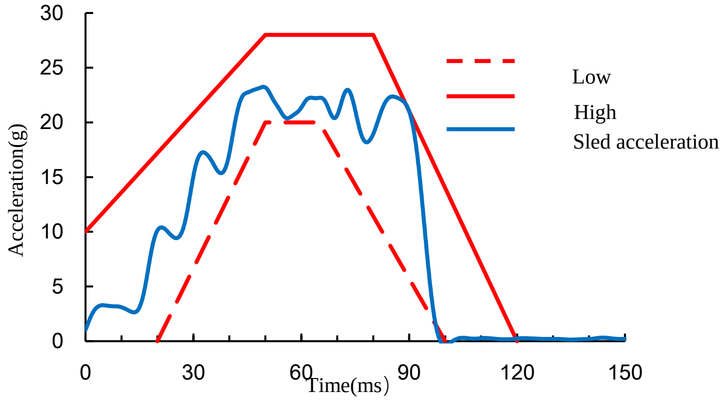

Fig. 6.Sled acceleration

3.2 Comparison of the kinematics behavior and injury assessment values of the Hybrid III 3YO dummy model and the test

The kinematics behaviors of the Hybrid III 3YO dummy and Q3 test dummy in the 5-piont harness CRS are compared in Figure 7. From the comparison of kinematics response, FE simulation results correspond well with the sled tests results. The ISOFIX and supporting leg are effective for preventing installation of the CRS on an ECE seat. The pelvis and shoulders are restrained by the lap and shoulder harnesses. Due to head movement, the neck flexed and the chin made contact with the chest from 78ms to 130ms.

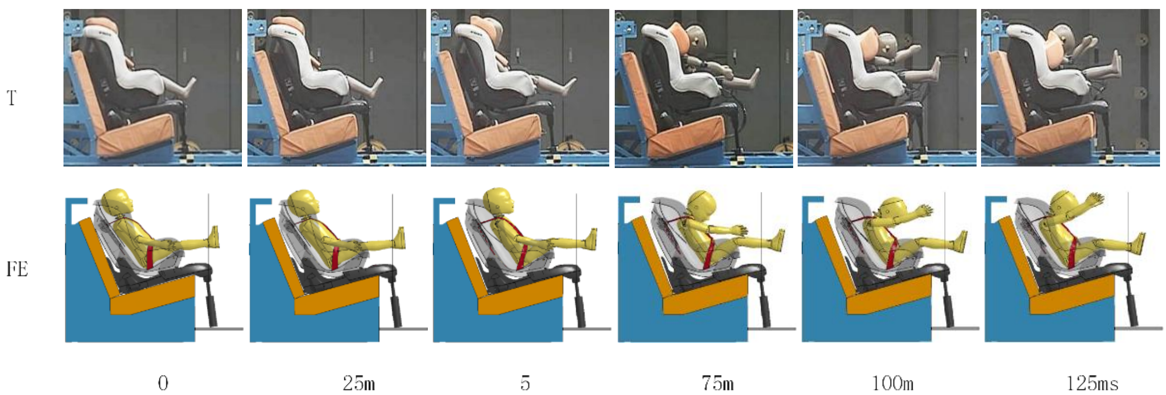

Fig. 7. Comparison of the kinematics behavior of the Hybrid III 3YO dummy and test (Q3)

Figure 8 shows the comparison of the chest and head resultant acceleration of Hybrid III 3YO dummy and test. The head and chest accelerations of the Hybrid III 3YO dummy are similar to those of the Q3 test dummy

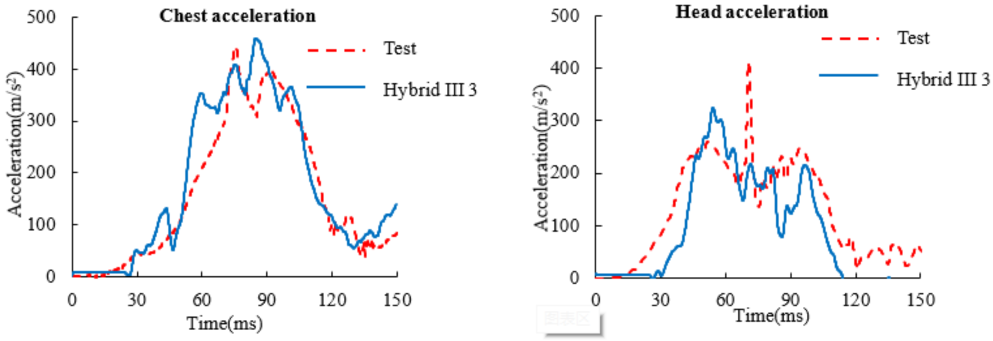

Fig. 8. Comparison of chest and head resultant acceleration of Hybrid III 3YO dummy and test (Q3)

3.3 The equation of motion on the chest of Hybrid III 3YO

In this study, the resultant chest acceleration from a frontal impact were formulated theoretically using the external and internal forces acting on the Hybrid III3YO dummy chest. For Hybrid III 3YO dummy, shoulder harnesses applied to forces on the chest, and the pelvis was controlled by the shoulder harnesses. And the unrestrained head and the upper extremities swung forward due to inertia. The inertial forces of the head and the upper extremities continued to transfer to the chest (see Figure9). The chest acceleration of Hybrid III3YO dummy is generated by forces acting on the chest. The external forces are applied from the shoulder belt, while the internal forces are applied from the lower neck, shoulder joints and the upper lumbar spine. The thoracic region of the spine of the Hybrid III dummy model is a relatively rigid steel box. The equation of motion of the chest is expressed as:

$$m_{chest} \times a_{chest} = F_{neck} + F_{shoulder(l)} + F_{shoulder(r)} + F_{lumbar} + F_{harness(shoulder)} + F_{chin\text{-}chest} \qquad (1)$$

Where m_{chest} is the chest mass, a_{chest} the chest acceleration, F_{neck} the lower neck force, $F_{shoulder(l)}$ and $F_{shoulder(r)}$ the left and right shoulder joint force , F_{lumbar} the lumbar spine forces ,$F_{harness(shoulder)}$ the shoulder harness force and $F_{chin\text{-}chest}$ the chin-chest contact force.

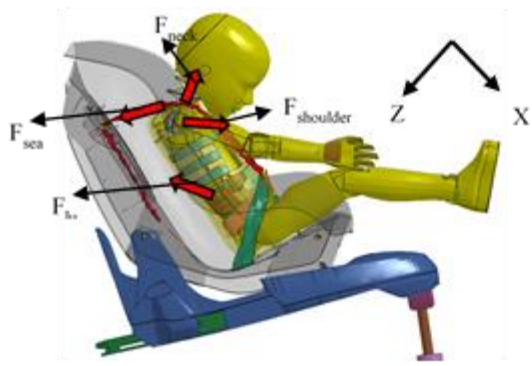

Fig. 9.Internal and external forces acted on chest

Figure10 shows the sum of the internal and external forces and the product of chest mass and chest acceleration for the Hybrid III3YO dummy. Since the chest coordinate system rotates with respect to the global coordinate system, the forward-rearward component of the force is the projection of the force vector in the x coordinate axis at each time. As shown in Figure10, the sum of forces $\sum F$ coincides with the product of chest acceleration and mass (ma_x). It can be seen that the forces of both the right and left shoulder joints ($F_{shoulder(r)}$, $F_{shoulder(l)}$) are positive for dummy since the upper extremities applied the force in the forward direction to the chest. The lower neck force F_{neck} is also positive as the head moves forward relative to the chest. At 70ms, the chin began to contact the chest, the chest acceleration and upper neck force in x direction decline slightly and the contact force reaches a maximum at 83ms.And after 83ms, the relatively large force of neck was decreased along with reducing force of the chin made contact with the chest. Because of the constraint of the lap belt, the flexion of lumbar is not very intense.

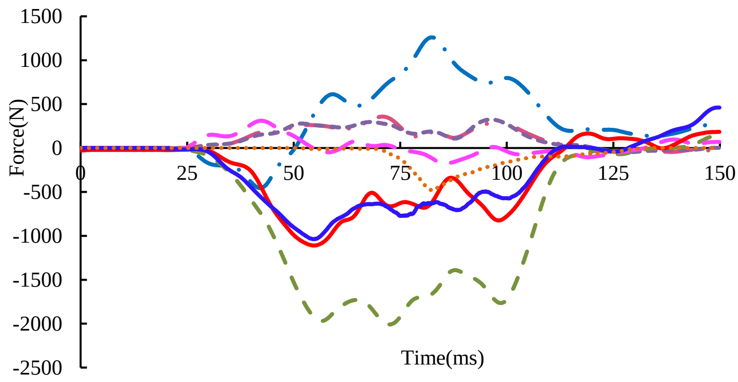

Fig. 10. The forces on chest of Hybrid III 3YO dummy (in forward x direction)

4 Conclusion

In this research study, the sled-CRS FE model in frontal impact base on ECE R44 was established and theoretical formula of chest loadings was analyzed for Hybrid III3YO dummy for the 5-point harness in ISOFIX CRS. The chest acceleration of Hybrid III 3YO dummy is generated from the external forces (shoulder harness) and the internal forces (lower neck, shoulders and upper spine), which the seatbelt force and the neck force have more proportion. The result shows that the sum of forces coincide with the inertia force (ma_x), which indicates the equation of motion can be used to examine the loadings on dummy chest. Although the internal and external forces are not included in the chest injury evaluation system, the forces exerted on chest has an effect on the chest acceleration. According to the force analyzing of chest, the loadings on the chest of the dummy can be calculated and determined whether the force is balanced.

As for the FE model, there existed some limitations. For example, the Hybrid III 3YO dummy has a low degree of biological resemblance relatively. The Hybrid III neck loadings in the dynamic test may be overestimated due to the stiff thorax spine. Further research is needed to investigate the neck loadings for child dummy with higher biological resemblance.

5. Acknowledgements

The authors would like to acknowledge support of the Funding of the State key Laboratory of Vehicle NVH and Safety Technology (NVHSKL-201606), The National Natural Science Foundation of China (Project No: 51675454), the Natural Science Foundation of Fujian Province, China (Project No: 2016J01748). Science & Technology Innovation Project of Fujian Province, China (Project No: 2016H2003)

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