ISB 2013 BRAZIL
XXIV CONGRESS OF THE INTERNATIONAL SOCIETY OF BIOMECHANICS
XV BRAZILIAN CONGRESS OF BIOMECHANICS

ANALYSIS OF THE POSSIBILITIES OF MITIGATING THE EFFECTS OF HEAD-ON COLLISIONS ON CHILDREN TRANSPORTED IN CAR SAFETY SEATS FIXED ROTATIONALLY RELATIVE TO THE CAR CABIN

Mirosław Świetlik, [1]Cezary Rzymkowski and Krzysztof Kędzior
Warsaw University of Technology, Institute of Aeronautics and Applied Mechanics, Warsaw, Poland
[1]Corresponding author; email: czarek@meil.pw.edu.pl

INTRODUCTION

The basic means of protecting the children transported in cars are special car safety seats introduced in the USA in 1970s. It has been established that effective protection in case of a car crash can be achieved by fastening the child to the cabin frame as its deformation can partially absorb the impact energy. Along with the efforts to improve the construction of traditional car safety seats, works are continued to find new solutions based on the concept of the seat and the child rotation relative to the car cabin in case of traffic collision. The concept is to mitigate the collision impact on the child by converting a portion of kinetic energy into rotational motion [1-3].

The study provides a comparative analysis of the possibility of mitigating the effects of head-on collisions on children transported in passenger cars in special safety seats fixed rotationally (Figure 1) relative to the car cabin *PCSS* (*Pivoted Child Seats System*) as compared to traditional safety seats fixed as stiffly as possible to the cabin frame – e.g. the system *ISOFIX* equipped with a device counteracting the rotation (support leg) – *FCSS* (*Fixed Child Seats System*). In the present case the seat movement has been limited to swivelling on one axis perpendicular to the car symmetry plane.

METHODS

The basic testing method adopted was a computer simulation based on the *MADYMO* system [4] – universally used software for researching passive safety systems in cars. The child was modelled with the use of an "ellipsoid" dummy available in the *MADYMO* system base: *Hybrid III 3-year-old Child Dummy* fastened to the car safety seat with a five-point harness. The seat harness belts were modelled using *shell* type elements. The seat geometry was recreated by 3D scanning of the commercial version of the safety seat type *GO/1 ISOFIX* and modelled with elements of the "*facet surface*" type. In the simulation model special constructional elements were included, which were indispensable for the practical execution of a controlled rotational motion of the safety seat relative to the rear car seat. The safety seat motion during the collision is controlled due to the application of a specific braking torque T_b in the revolute joint.

RESULTS AND DISCUSSION

Simulation tests were carried out for a scenario relevant for head-on collisions of typical passenger cars, with a rigid obstacle, at the speed of 50 km/h. For this purpose the time span of acceleration impulse was applied (fulfilling the requirements of the *ECE R44.03* [8]), that was measured during one of the *sled-test*-type experimental tests [5] which had been carried out earlier.

To assess the injury risk for a child a special synthetic index of injury risk *Snr* [9] was applied. *Snr* was defined as a sum of twelve selected standardized biomechanical injury criteria calculated based on collision simulation results in the *MADYMO* program.

Reference values of individual criteria, considered as critical for a three-year old child, were adopted based on literature data [4, 6, 7].
With the use of the *Snr* index, a percentage index for safety improvement was defined – *SFI (Safety Factor Improvement)*, which makes it handy to compare the benefits of using a *PCSS* safety seat – fixed rotationally – and a fixed seat (*FCSS*), as follows:

$$SFI = 100\% * (Snr_{Fix} - Snr)/Snr_{Fix},$$

where: Snr_{Fix} stands for the value of the *Snr* for a fixed seat.

Possible practical limitations of the *PCSS* solution were examined by analyzing the sizes of the motion zones *PLR (Plane Motion Range)* by projecting the trace of the movement of the seat with the child in it onto the longitudinal car symmetry plane. The comparison of motion zones of the *FCSS* and *PCSS* models (for a selected point of placement of the joint) are shown in Figure 1. Maximal transfers of child's head L_{hx} in the XZ plane were analyzed with special attention to conformity with [8]. The size of this transfer can be treated both as a factor in injury risk assessment and as a hint for designing the seat fixing in a particular model of a car.

Based on the results of the collision simulation tests achieved for the *FCSS* model (index value $Snr = Snr_{Fix} = 6.5$, and motion zone PLR_{Fix}) levels of reference for the comparative analysis were determined. Parametric research of the *PCSS* model was carried out for 18 locations of joint pivot axis against the seat main body (Figure 1) and a dozen or so (for each of the pivot axis locations) values of the braking torque (friction) T_b in the joint. As a result of the simulation for each of the 18 locations of the joint the best solution was determined Si={T_b, α_{max}, *Snr, SFI, PLR,* L_{hx}}.

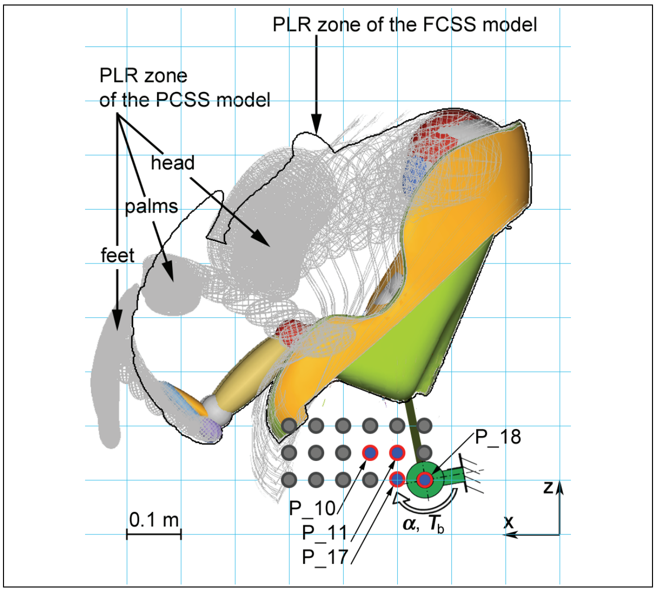
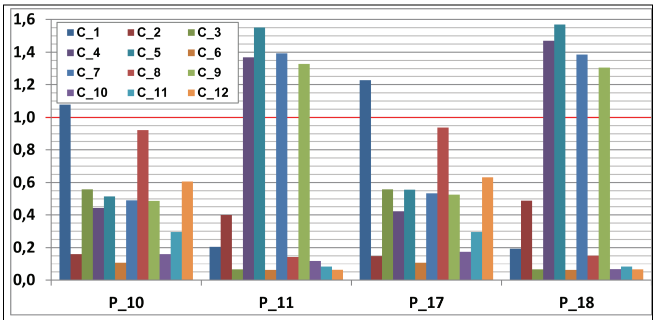


Figure 1: Example of comparison of *Plane Motion Ranges* for the *PCSS* and *FCSS*.

Also considered in the process of ensuring the highest possible *SFI* value, were the benefits of the lowest possible increase in the motion zone of the child together with the pivotal seat, in comparison to the stiffly fixed seat (the smaller this zone is, the bigger the potential group of cars where the pivotal seat will fit without major seat alterations).

For the four thus selected potentially best locations for the pivot point, an analysis was carried out of the individual biomechanical injury criteria (partial criteria, on the basis of which the *Snr* index is determined). What was taken into consideration were the relations between the values achieved and the values considered as critical [5-7] and also the relative advantage in comparison to the fixed seat (Figure 2).



C_1 – 3ms thorax acceleration, C_2 – Head Injury Criterion (HIC), C_3 –neck tension negative, C_4 – neck tension positive, C_5 – neck shear negative, C_6 – neck shear positive, C_7 – neck bending negative, C_8 – neck bending positive, C_9 , C_10, C_11 and C_12 – combined force/torque neck injury predictors [4]

Figure 2: Values of the 12 biomechanical injury indexes for the seat fixed on joints at points P_10, P_11, P_17 and P_18 relative to the individual values for the stiffly fixed seat.

This analysis made it possible to narrow down the choice to two locations of the pivot point, which – with the preservation of the safety improvement index (*SFI*) at about 50%, a limited size of the motion zone and a reduction of all the relevant partial criteria – do not pose constructional problems (points P_10 and P_17). Visible here is the major reduction of all the partial criteria, except C_1 (the 3ms criterion of acceleration for the thorax), which reaches small values in comparison to the critical values both in the case of the pivotal seat and the fixed seat, so its minor increase does not pose a problem.

For thus selected points (P_10 and P_17) experimental research shall be carried out, that will make it possible to formulate final conclusions on the potential effectiveness of the proposed solution.

CONCLUSIONS

Simulation tests demonstrated significant possibilities of child injury reduction as a result of the application of the pivotal seat (*SFT* index value at about 50%). Should the first *sled-test*-type experimental research confirm these very optimistic results, it will be possible to progress into the next phase – designing and constructing a “technology demonstrator” in the form of a pivotal seat placed in a selected, mass-produced passenger car and carrying out a full-scale crash test.

ACKNOWLEDGEMENTS

Paper funded by the grant No. N N509 573939 of the Polish Ministry of Science and Higher Education.

REFERENCES

1. WO2007070429 – Spherically Guided Seating System, EPO, 2006-2009.
2. http://www.safetyegg.com/
3. US Patent 6439660 – Kinetic child restrain device, 2002.
4. MADYMO *Manuals*, ver. 7.3, TNO Automotive, Delft, The Netherlands, 2010.
5. P. Kurpiewski, *Dynamical experimental tests versus other methods in investigation of effectiveness provided by child restraint systems in cars*. M.Sc. thesis, Warsaw University of Technology, Warsaw, Poland, 2007.
6. N. Yoganandan et al, Pediatric Biomechanics, in: Nahum A.M., Melvin J.W. (eds), *Accidental Injury Biomechanics and Prevention*, Springer-Verlag New York, 2002, pp. 550–587.
7. *Crash Analysis Criteria Description*, version 2.1.1, Workgroup Data Processing Vehicle Safety in cooperation with the Task Force ISO TS 13499 (ISO-MME), 2005.
8. UN/ECE Regulation No 44 — Uniform provisions concerning the approval of restraining devices for child occupants of power-driven vehicles (‘Child Restraint Systems’), *Official Journal of the EU*, 9.9.2011.
9. Świetlik M., Kędzior K., Rzymkowski C: An Attempt to Assess Efficiency of Movable Type Child Restraint System in the Event of Car Road Collision, *Proc. of ICRASH 2012 Conference*, Milano, Italy, 2012.