INFLUENCE OF THE TYPE OF A CHILD RESTRAINT SYSTEM USED ON THE KINEMATICS AND LOADS OF A CHILD IN A MOTORCAR DURING A FRONTAL IMPACT

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Summary

An analysis of road accident reports and surveys concerning this issue show that children aged from 8 to 12 years are often improperly carried in cars. In defiance of the regulations in force, some parents protect their children exclusively by fastening the standard seat belts intended for adults. The paper presents an analysis of results of experimental tests aimed at the assessment of influence of the type of a child restraint system (CRS) used on the effectiveness of operation of a seat belt during a frontal impact. Attention was focused on the positioning of the seat belt in relation to the child in association with the dynamic load and kinematics of the child. The experiments were carried out with the use of a P10 test dummy representing a child aged about 10 years. Three CRS types used with the test dummy were considered: the dummy was placed directly on the car seat, on a booster cushion (without a backrest), and on a booster seat (with a backrest). The dummy was fastened with the use of a standard seat belt. The experiments were carried out on a crash test stand at the Automotive Industry Institute (PIMOT) in Warsaw.

The results obtained have revealed important relations between the CRS type used and the observed loads of the head and torso of the dummy. They have confirmed that the child protection should not be limited to mere use of a seat belt for adults because the seat belt positioning in relation to the child's body not only adversely affects the effectiveness of the seat belt operation but also may cause injuries to child's abdomen and neck.

Keywords: road transport, vehicle safety, seat belts, child safety, booster seat

1. Introduction

In Poland, 2 296 children aged from 0 to 14 years were killed in road accidents in the period from 2000 to 2012. The number of such deaths regularly declines, from 265 in 2000 to 89 in 2012 (31 and 58 in age brackets from 0 to 6 years and from 7 to 14 years, respectively) [6, 17]. The number of deaths of children aged from 0 to 14 years per 1 million of the population of children in the same age brackets decreased from 36.3 in 2000 to 15.3 in 2012, which

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confirms substantial improvement in the safety of children in road traffic. According to other data, the value of this indicator is markedly higher in Poland than its average value in the European Union:
- In 2006: 24.7 in Poland (population of 6.1 million) as against 18.8 in the UE [17];
- In 2009: 22 in Poland (population of 5.7 million) as against 12.0 in the UE [6].

Children aged from 0 to 14 years are killed in road accidents chiefly as passengers of motorcars.

The influence of the type of a child restraint system (CRS) used for a child aged about 10 years on the dynamic loads acting on the child and on the risk of injury to the child during a frontal impact was assessed in publication [19]. The three CRS types considered here have been illustrated in Fig. 1.

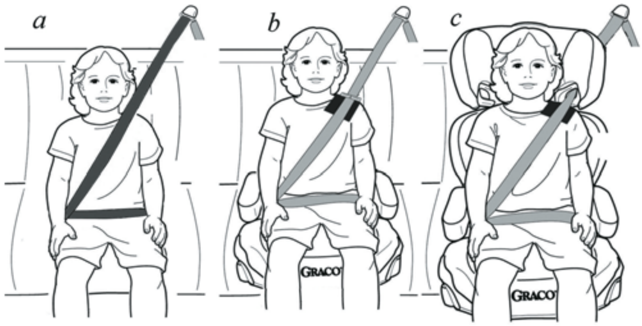

Fig. 1. Three motorcar CRS types considered (sketch based on [11]), where the child was seated: a) directly on the car seat; b) on a booster cushion; c) on a booster seat (with a backrest)

It was pointed out that the P10 test dummy representing a child aged about 10 years, placed directly on the car backseat, was exposed to very high dynamic loads during a frontal impact. In spite of the seat belt having been fastened, the risk of a severe head injury (AIS4+) was as high as 70%. When the dummy was placed on a booster cushion or booster seat (without or with a backrest, respectively), the risk of a head injury was on a level of 3÷5% only. Attention was also drawn to alarmingly high acceleration of the torso of the dummy belted on a booster seat (with a backrest) [19].

This paper is to show how individual CRS types mentioned above affect the operation of seat belts and, in consequence, the dynamic loads and kinematics of the child. The description of crash tests will be preceded by an analysis of the literature dealing with the methods of carrying children in motorcars.

2. How are children transported in motorcars?

Children are usually transported on rear seats. The rules of transporting children in motor vehicles are laid down in the "Road Traffic Law" Act. One of the legal requirements is that a child aged up to 12 years, not more than 150 cm tall, should be transported in a safety seat appropriate for the child's weight and height. The carrying of a child in a rearward-facing safety seat placed on a front seat of a car provided with an airbag is legally forbidden. On the other hand, the transporting of older children on the front passenger seat is legally permitted.

The data on the transporting of children by car are usually sourced from road accident reports or surveys concerning this issue. The relations between the risks of injury to children transported on the front and rear car seats have been assessed in publication [1], where data collected from about 11 thousand road accidents involving almost 17 thousand children aged up to 15 years have been taken into consideration. The accidents examined made about 5% of all the accidents with children that occurred in 16 states of the USA in 1998÷2007. This study confirmed the recommendation that children aged up to 12 years should be transported on the rear seats even in the cars provided with the most recent safety systems designed for adult occupants of the front seats. The children occupying seats in the rear seat row(s) suffered injuries of the (AIS2+) severity degree with almost two times lower frequency than it happened in the case of children sitting at the front, regardless of the collision type. Similar results were obtained for children aged 9÷15 years at the research work reported in publication [3]. The trends in changes in the safety of passengers, including children, of the front and rear seats of motorcars during road accidents were earlier described in publication [20].

In Europe, only every third child is adequately protected when being transported by car, according to estimates [7]. As regards road accidents involving children in Poland, detailed data such as the seat occupied by the child involved, collision type, CRS type used, etc., are not available. According to surveys, more than 90% of parents properly transport their babies aged from 0 to 1 year, but for children in age brackets from 4 to 12 years, this percentage drops to mere 52% [2].

The structure of the CRS types used vs. child age, prepared on the grounds of "CREST Accident Data Base (Child Restraint Systems for Cars)" [8], has been presented in Fig. 2. According to these data, even very little children are often restrained by their parents with the use of standard seat belts (SB).

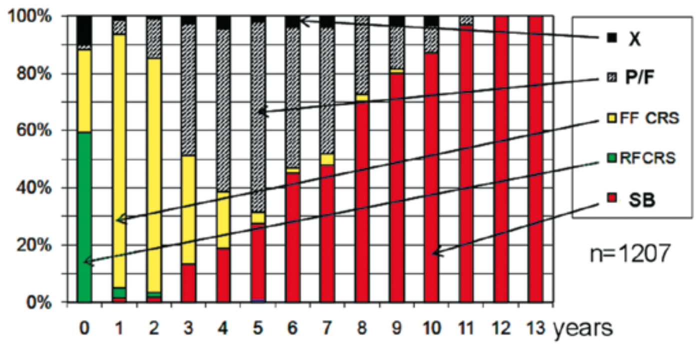

Fig. 2. The use of different CRS types for children vs. child age [8]: SB – standard seat belt only; RF CRS / FF CRS – rearward-facing / forward-facing child safety seat; P / F – booster cushion / booster seat (with a backrest); X – other system

The methods of transporting children aged from 4 to 8 years to and from schools and kindergartens were researched in the USA in 2000÷2001. The research revealed that 80% of the youngest children were transported in child restraint systems appropriate for child's age while only 55% of the older children were properly protected with the use of a seat belt for adults, i.e. with the child sitting on a booster cushion or booster seat [5]. In a survey carried out in the USA in 2012, all the parents (1 612) declared their children aged 4 to 5 years to be transported on booster seats, while this method was declared for only 37% of children in age brackets from 7 to 8 years [9]. According to the survey described in [4], only 24% of children aged from 4 to 11 years were transported by their parents on a booster seat or a booster cushion while standard seat belts alone were used in the case of the other 76% of the children. On the average, the children transported on booster cushions or booster seats were much younger (5.8 vs. 8.2 years), lighter (21.9 vs. 30.3 kg), and shorter (115 vs. 131 cm) in comparison with the children transported directly on a car seat with having been fastened with a standard seat belt.

The results of research carried out in urban traffic in Germany have confirmed that older children (6 to 12 years) riding in a car are very often fastened with nothing but a seat belt for adults (Fig. 3). In 2004, the percentage of children thus transported was about 40% while in 2009, it dropped to 20% only. Several per cent of children travel without any protection means being used at all.

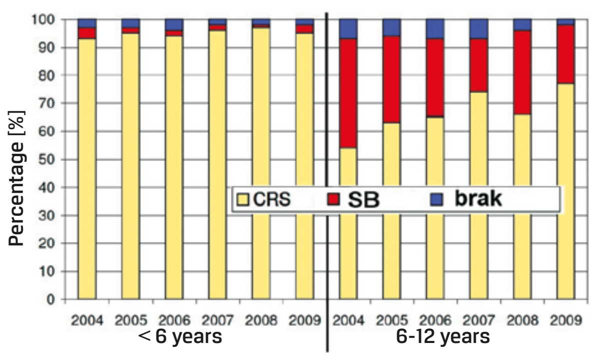

Fig. 3. The use of different child protection means on rear car seats in urban traffic in Germany vs. child age [7]: CRS – child restraint systems; SB – seat belts

The data presented above show that the older a child is, the less attention is paid by its parents to its safety in a car. A frequent parent's fault is the restraining of too small children with the use of a seat belt for adults. This situation is made even worse by the fact that most children older than 8 years fasten their seat belts by themselves. The same is always or sometimes done by as many as 40% of younger children, aged from 6 to 8 years [12].

In the European Union, the activities for the safety of children in motorcars are coordinated within a program named COVER (Coordination of Vehicle and Road Safety Initiatives). They are concentrated in such projects as *Child Advanced Safety Project for European Roads* (CASPER) and *Enable Protection for Older Children* (EPOCh) [14, 15].

3. Scope of experimental tests

In the experimental tests, attention was focused on the loads of the head and torso of the P10 dummy representing a child aged about 10 years. The tests were carried out on a crash test stand AB-554 at the Automotive Industry Institute (PIMOT) in Warsaw [13, 18]. The body of a passenger car was brought up to a speed of about 48 km/h and then rapidly stopped, within a time of about 100 ms. The time history of the car body deceleration was in conformity with the requirements laid down in UN ECE Regulation No. 44, which is applicable to the testing of child restraint systems. The maximum car body deceleration was about 22 g. In the successive crash tests, high repeatability of the body deceleration was achieved, which is a matter of critical importance for the subsequent analysis.

The P10 dummy was placed on the left rear seat and it was fixed with the use of a standard seat belt, which was replaced after every crash test with a new one. During the tests, the dummy was seated:

- directly on the car seat (test B);
- on a booster cushion (without a backrest) (test P);
- on a booster seat (with a backrest) (test F).

The booster cushion (test P) and the booster seat (test F) have been shown in Fig. 4. The armrests were set to the upper position (about 15 cm above the seat plane). The backrest was extended to its maximum height (81 cm) and the seat belt strap was placed in the seat belt guide incorporated in the headrest.

Fig. 4. Booster cushion *Graco* Booster and booster seat *Graco Junior Maxi Plus* [10]

The use of different child restraint systems in tests B, P, and F has an impact on the position of the dummy, position of the seat belt in relation to the dummy, and lengths of the lap and shoulder portions of the seat belt (Fig. 5). Some dimensions defining the position of the dummy in relation to the car and the position of the seat belt strap in relation to the dummy have been given in Fig. 6 and in Table 1.

The most important differences in the dummy's positions in tests B, P, and F are related to the height of the dummy in relation to the rear seat of the car, inclination of dummy's torso, thighs, and shanks, position of dummy's shoulder in relation to the upper seat belt anchorage point (points R and Q in Fig. 5), and lengths of the lap and shoulder portions of the seat belt strap.

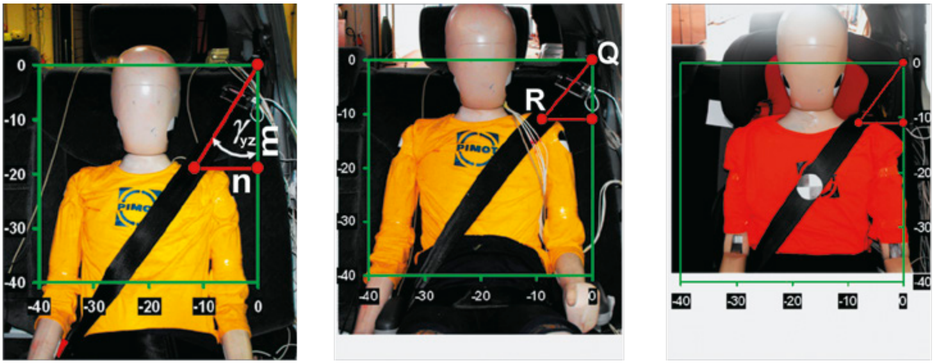

Fig. 5. The P10 dummy before tests B, P, and F (proceeding from left to right)

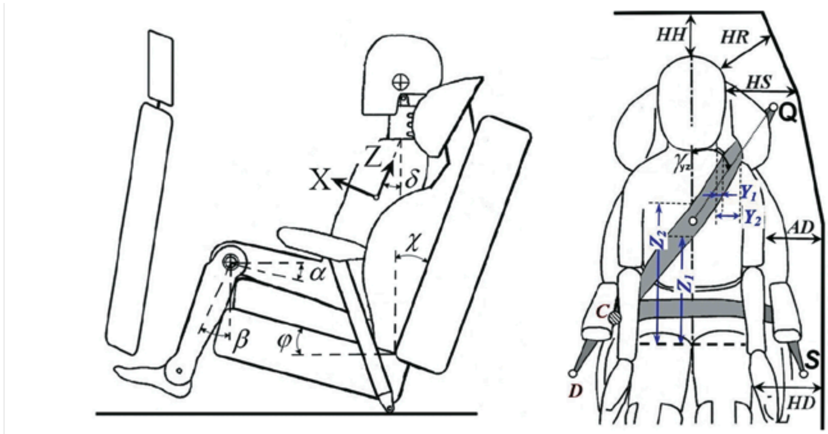

Fig. 6. Dimensions defining the dummy and seat belt positions before the crash tests (sketch based on [16])

Table 1. Dimensions defining the positions of the dummy and the seat belt

Dimension	Test B	Test P	Test F
Rear seat backrest and cushion inclination angles χ / φ [deg]	26 / 20		
Dummy's torso inclination angle δ [deg]	42	35	23
Left / right thigh inclination angle α [deg]	25/25	20/20	21/21
Left / right shank inclination angle β [deg]	40/43	33/33	35/35
Shoulder belt inclination angle γ_{yz} (wg rys. 5) [deg]	31	39	36
Distances n / m (see Fig. 5) [deg]	19/12	11/9	11/8
Distances HH / HR / HS [cm]	23/20/22	12/13/16	11/11/12
Distances AD / HD [cm]	16/24	14/22	13/20
Distance between the belt strap and the thighs Z1 / Z2 [cm]	30/22	29/21	28/21
Distance between the belt strap and the neck Y1 / Y2 [cm]	3/9	5/11	4/9
Lengths of belt strap sections CD / CQ / CS [cm]	22/77/63	22/79/74	22/85/76

4. Dynamic loads acting on the dummy

The following quantities were measured during the crash tests:

- Accelerations of dummy's head and torso in three mutually perpendicular directions;
- Tensile forces in the lap and shoulder portions of the seat belt;
- Accelerations of the booster cushion and booster seat in three mutually perpendicular directions.

In addition to the above, the dummy's motion was recorded with the use of high-speed cameras (1 000 frames/s). The results of measurements of dummy's head and torso accelerations have been shown in Fig. 7. Individual curves in the graphs represent acceleration components measured in three mutually perpendicular directions. Due to the initial lean of the dummy in the sagittal plane (XZ), the X axis of the acceleration sensors installed in dummy's head and torso was not horizontal and the Z direction was not vertical (cf. Fig. 6). During the impact, the positions of sensor axes in relation to the car body floor changed with changes in the dummy's torso and head bend angles.

Attention is drawn by distinct differences in the curves representing the time histories of individual acceleration components in directions X, Y, and Z in tests B, P, and F. The highest values of the head and torso accelerations could be observed during the forward movement of the dummy, within the period of up to about 120 ms. In the initial phase of the impact (up to 30÷40 ms), before the seat belt forces were applied to the dummy, the dummy moved along the seat, in a direction almost parallel to the car body floor. Since the friction force developing between the dummy and the seat was insignificant, the dummy's velocity direction and value remained almost unchanged, i.e. the acceleration value was near to zero. Along with the seat belt being stretched, the acceleration of the dummy increased. In all the tests B, P, and F, the torso acceleration component X and the head acceleration component Z predominated, with the head becoming significantly bent in relation to the torso.

In tests P and F, the time histories of the head acceleration (i.e. the X and Z components) were qualitatively similar to each other, while those recorded in test B clearly differed from them. For test B, a frame-by-frame analysis of the video record has shown that the dummy was lifted off the seat (positive values of the Torso-Z component at the time of 70÷100 ms, see Fig. 7a); then, the torso was rapidly stopped and the head was considerably bent. In the period from 95 to 120 ms, the dummy dropped onto the seat (negative values of the Torso-Z component).

In all the tests, two peaks could be seen in the head acceleration component curves. The first one, observed in the period from 70 to 110 ms, occurred in the forward motion of the dummy. The other one observed in tests B and P at the instants of 180 ms and 220 ms, respectively, resulted from the impact of dummy's head against the rear seat backrest when the dummy moved backwards. In test F, on the other hand, the peak at the instant of 140 ms was caused by the impact of the head against the left thigh and the head did not hit the backrest of the rear seat.

The results of torso acceleration measurements (Fig. 7) were affected by the initial torso inclination angle (Table 1). In test B, the torso was inclined by 42 deg from the vertical plane.

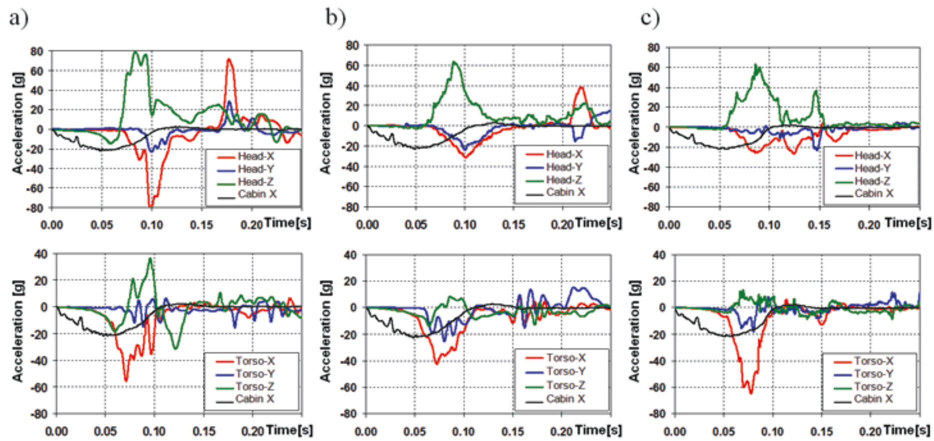

Fig. 7. Accelerations of the head and torso of the P10 dummy in tests B, P, and F (proceeding from the left)

The inertia force acting on the dummy's torso was directed horizontally (in accordance with the direction of vehicle motion); therefore, the X and Z acceleration component values remained almost equal to each other until the instant when the torso inclination angle began to change (i.e. to about 60 ms). In tests P and F, the value of the Z acceleration component in the same time interval was significantly lower than that observed in test B because of smaller torso inclination angle. The Y component was chiefly caused by rotation of the dummy around axis Z. This rotation is well visible in the video record of test P.

5. Load of the seat belt

During the retarded motion of the car, the inertia force acting on the dummy is directed longitudinally (according to the direction of vehicle motion). It is chiefly balanced by forces developing in the seat belt (the reaction forces applied to dummy's legs and the friction of the dummy against the seat are of minor importance).

Realizations of the tensile forces in the seat belt strap have been shown in Fig. 8. The load cells measuring the tensile force in the seat belt strap were installed in the QR and ST belt strap sections (cf. Fig. 10). Realizations of the forces in the lap and shoulder belt portions (LB and SB, respectively) have been presented separately from each other. In tests B, P, and F, the force in the shoulder belt portion increased with different rates but both the maximum values of this force and the times when the maximums occurred were similar to each other as appropriate. For the lap belt portion, the force vs. time curves distinctly differed from each other, in terms of both the maximum values and the time of occurrence of the maximums.

The interpretation of differences in the loading of the seat belt in tests B, P, and F have been based on an analysis of the dummy's motion (frame-by-frame analysis of the video records). The dummy's positions at several points in time have been illustrated in Fig. 9. In

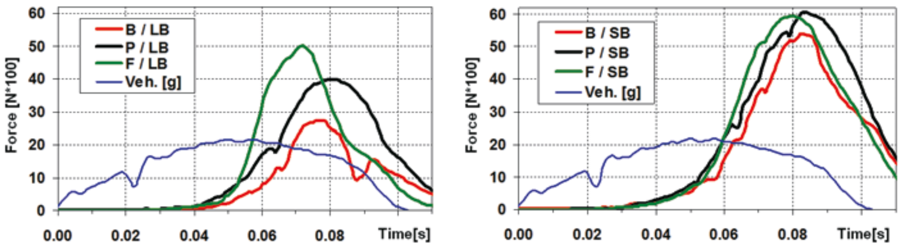

Fig. 8. Tensile forces in the seat belt strap: LB – lap belt portion; SB – shoulder belt portion; Veh. – vehicle deceleration; the graphs cover a force range of up to 6 000 N

tests B and P, the rearward dummy's head motion began at an instant of about 110 ms as against 160 ms recorded for test F.

In test B, where the dummy was placed directly on the rear car seat, the lap belt portion was situated too high above the thighs. It can be seen in the video record that the hips were significantly displaced relative to the car seat during the impact. The lap belt portion slipped from the thighs and hips to dummy's abdomen and, further, to the area under the ribs (Fig. 9). This was reflected in a temporary drop in the force in the lap belt portion at an instant of 85÷95 ms (Fig. 8). In test F, there was a booster seat backrest behind dummy's back and the dummy was situated further ahead of the car seat backrest than it was in tests B and P. Such a position of the dummy resulted in steep growth in the force loading the lap belt portion.

In test B, the torso did not reach its vertical position because of significant displacement of the hips to the front (at 95÷115 ms). In test P, when the torso position was almost vertical, the torso rotated leftwards and the belt almost fully slipped from the shoulder onto the arm. In test F, the torso bent forward to the greatest extent, until the head hit on the left thigh. This was because of the hip motion being restrained by the lap belt portion, in which the tensile force reached its maximum most quickly (Fig. 8). Interesting was also the motion of dummy's hips in tests P and F, where in the period 85÷110 ms the hips moved rearwards although the head still moved to the front.

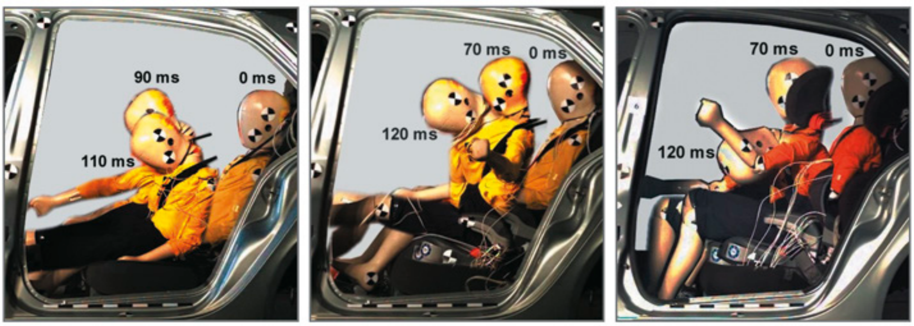

Fig. 9. Positions of the dummy at several instants in tests B, P, and F (proceeding from the left)

Based on measurements of locations of the seat belt anchorage points and the frame-by-frame analysis of the video records, the seat belt positions relative to the dummy were determined. This was done with the use of a dimensional grid marked on dummy's silhouette in a way as shown in Fig. 10, where characteristic points of the dummy and seat belt positions were marked as well. The origin of the coordinate system is at the point of anchorage of the left end of the lap belt portion to the car body (point S).

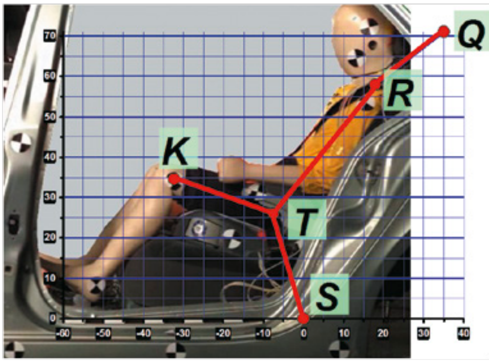

Fig. 10. Method of determining dummy's displacement

A change of the child restraint system (CRS) type used resulted in a change in the dummy's position relative to the car seat and this affected the directions of placement of the QR and ST seat belt sections (Fig. 10). The directions of the measured tensile forces in the shoulder and lap belt portions (F_S and F_L, respectively) are different from that of the inertia force acting on the dummy. The values of component forces F_{Sx} and F_{Lx} depend on the position of the seat belt strap relative to the dummy (Fig. 11):

$$F_{Sx} = F_S \cdot \cos\gamma \cdot \cos\gamma_{xy} \tag{1}$$

$$F_{Lx} = F_L \cdot \cos\beta \cdot \cos\beta_{xy} \tag{2}$$

where: $\gamma, \gamma_{xy}, \beta, \beta_{xy}$ – angles defining the position of the shoulder and lap belt portions.

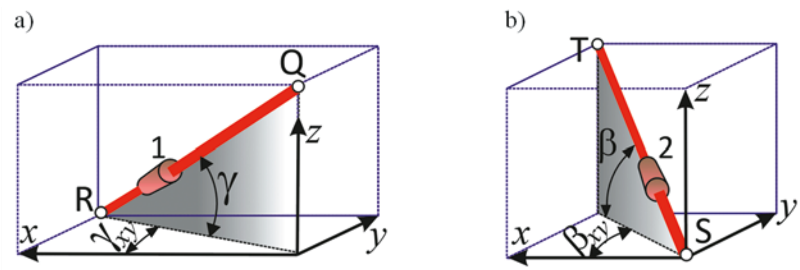

Fig. 11. Positions of the shoulder (a) and lap (b) belt strap portions relative to the dummy: Q, S – points of anchorage of the shoulder and lap belt portions to the car body; R, T – points of contact of the shoulder and lap belt portions with the dummy (cf. Fig. 10); 1, 2 – load cells to measure forces in the shoulder and lap belt portions

Figs. 12 and 13 show positions of the characteristic points defined in Fig. 10 at two time instants:

t_o – time when the dummy was in its initial position (dashed lines);
t_{LB} – time when the tensile force in the lap belt portion reached its maximum value (solid lines).

The values of the angles defining the position of the belt strap at the t_{LB} time instant have been specified in Table 2. For varying CRS types, the biggest differences in the belt position relative to the dummy were observed for the shoulder belt portion, especially in the γ_{xy} angle value (Fig. 12b). The position of the belt on dummy's shoulder (point R) was not constant when dummy's torso was moving. In test B, the belt strap slipped towards the neck, while it moved towards the arm in tests P and F (Fig. 12b). Neither of these situations (visible also in video records) was favourable: in test B, the belt may cause injury to the neck; on the other hand, it may slip off the shoulder in tests P and F.

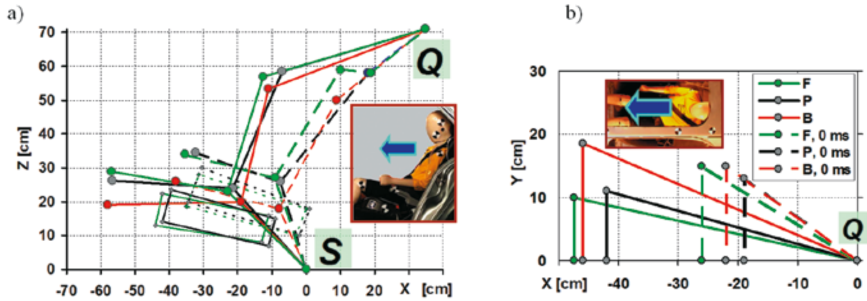

Fig. 12. Positions of the dummy and the booster cushion and booster seat relative to the seat belt anchorage points, in planes XZ (a) and XY (b): dashed lines – before the test; solid lines – during the impact

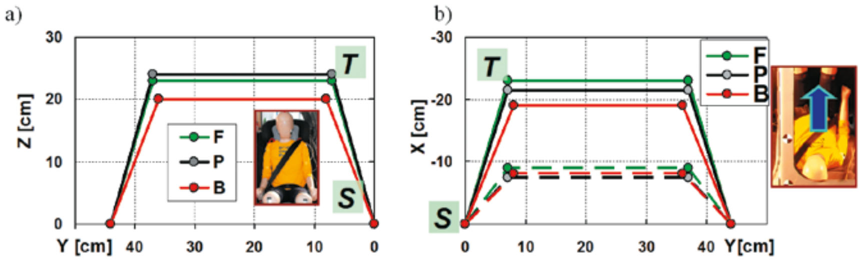

Fig. 13. Position of the lap belt portion in planes XZ (a) and XY (b): dashed lines – before the test; solid lines – during the impact

Equations (1) and (2) may be used for determining what part of the measured seat belt forces F_S and F_L balances the dummy inertia forces. With this end in view, coefficients $k_S = F_{Sx}/F_S$ and $k_L = F_{Lx}/_{FL}$ were calculated (Table 2). Their lowest values occurred in test B, where the shoulder belt portion was tensioned with a strong force, but the effectiveness of the dummy protection by the belt in this configuration was reduced. High values of coefficients k_S and k_L in tests P and F confirm the advantages of the use of booster cushions or booster seats. The seat belt position relative to the child sitting in a higher location is in such a case more close to the position of the shoulder portion of a seat belt in relation to an adult. This means that the seat belt acts on the dummy more quickly and with a stronger force (cf. Fig. 8).

Table 2. Angles defining the seat belt position at the instant t_{LB}

Angle [deg]		Test B	Test P	Test F
Shoulder belt portion	γ	20	16	16
	γ_{xy}	22	15	12
Lap belt portion	β	44	47	44
		23	18	17
$k_S = F_{Sx}/F_S = \cos\gamma \cdot \cos\gamma_{xy}$		0.87	0.93	0.94
$k_L = F_{Lx}/F_L = \cos\beta \cdot \cos\beta_{xy}$		0.66	0.65	0.69

The seat belt position relative to the dummy during an impact is also influenced by interaction between the car seat and the booster cushion or booster seat. The initial position of the booster cushion or booster seat in tests P and F has been marked in Fig. 12a with dashed lines. The backrest of the booster seat did not affect the distance between its seat proper and the backrest of the car seat but it caused the dummy to be shifted forwards (by about 6÷8 cm), which resulted in the booster seat sinking deeper in the car seat cushion. During an impact, the booster seat moved along the car seat cushion and caused deflection of the latter. The deepest deflection, of about 6 cm, was observed at the instant when dummy's hips were pushed farthest to the front, with this having been illustrated by solid lines in Fig. 12a.

6. Kinematics of the dummy

Afterwards, attention was focused on dummy's displacements in relation to the rear car seat depending on the child restraint system used. The displacements were calculated by integrating the realizations of acceleration of the car body, booster cushion and seat, and dummy's torso in tests B, P, and F. The maximum car body displacement thus calculated was 65÷67 cm, which corresponded to the stopping distance directly measured on the brake of the test stand. The principal dummy's motion relative to the car seat in the initial phase of the impact was longitudinal displacement, i.e. displacement in the direction of vehicle drive. In consideration of the fact that the dummy's torso and booster cushion or seat were inclined, the calculations were carried out for the resultant acceleration determined from the X, Y, and Z components at an assumption made that the direction of the resultant acceleration was consistent with the direction of vehicle drive. The calculation results have been presented in Fig. 14a. The displacements of the dummy's torso and booster cushion and seat (i.e. of the points where acceleration sensors were installed) relative to the vehicle body floor have been given in Fig. 14b. The calculation results shown in Fig. 14b were verified by the frame-by-frame analysis of the video records, which produced comparable results (Table 3).

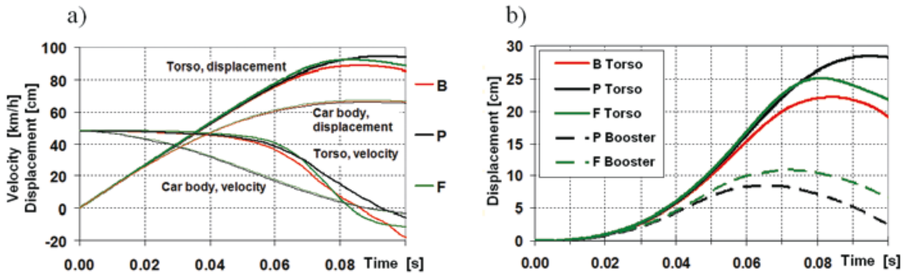

Fig. 14. Kinematics of the dummy in tests B, P, and F:
a) Velocity and displacement of the car body and dummy's torso relative to the ground;
b) Displacement of dummy's torso and booster seat relative to the car body floor

Table 3. Summarized results of calculations and measurements of dummy, booster cushion, and booster seat displacements

Maximum longitudinal displacement of:	Test	Results of calculations (Fig. 14)	Results of an analysis of movie records
- torso relative to the car seat	B	22 cm / 84 ms	22 cm / 84 ms
	P	28 cm / 92 ms	28 cm / 90-94 ms
	F	25 cm / 80 ms	25 cm / 80-82 ms
- booster cushion or booster seat relative to the car seat	P	8 cm / 65 ms	9 cm /68 ms
	F	11cm / 72 ms	11 cm /74 ms
- dummy's hips relative to the car seat	B	-	28 cm / 110 ms
	P	-	24 cm / 80 ms
	F	-	21 cm / 72 ms
- dummy's hips relative to the booster cushion or booster seat	P	-	15 cm
	F	-	10 cm

In Fig. 15, realizations of the displacements of dummy's torso, booster cushion, and booster seat have been compared with realizations of the forces acting in the lap and shoulder

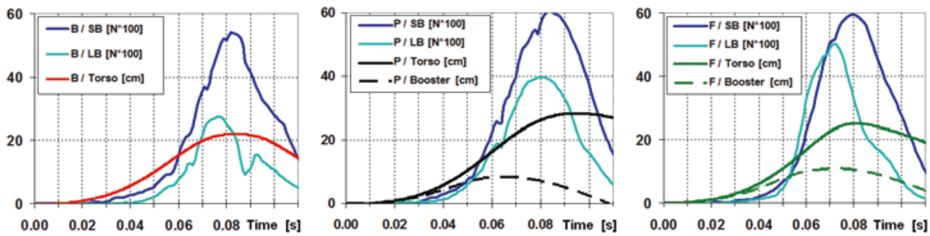

Fig. 15. Comparison between the seat belt forces and the displacements of dummy's torso and booster cushion or seat; the graphs cover a force range of up to 6 000 N

portions of the seat belt. The force in the lap belt portion reached its maximum values in tests B, P, and F at 76 ms, 80 ms, and 72 ms, respectively. In the shoulder belt portions, the maximums of the force occurred at 84 ms, 84 ms, and 80 ms, respectively.

Based on the analysis described above, the following findings were made as regards the dependencies between the seat belt load and dummy's movements in tests B, P, and F:

- The largest displacement of dummy's torso was observed in test P. The maximum of this displacement was delayed by about 10 ms as against the maximum of the force in the shoulder belt portion. This resulted from the dummy's torso rotation described previously and caused by the seat belt's reaction applied to the left dummy's shoulder. In tests B and F, the maximum displacement of dummy's torso took place simultaneously with the maximum of the force in the shoulder belt portion. The dummy's torso was most rapidly brought to a halt in test F, which is reflected in the highest deceleration of the torso motion (Fig. 7).
- The largest displacement of dummy's hips was observed in test B. This was because the lap belt portion slipped from the thighs and hips to dummy's abdomen at an instant of 85÷95 ms, which was reflected in a temporary drop in the force in the lap belt portion (Fig. 15). In tests P and F, the maximum displacement of dummy's hips took place simultaneously with the maximum force in the lap belt portion. The dummy's hips were most rapidly brought to a halt in test F, because the presence of a booster cushion or booster seat favourably affected the position of the seat belt strap relative to the dummy. In tests P and F, a significant difference was observed in the displacements of dummy's hips relative to the booster cushion or booster seat (the displacements were 15 cm and 10 cm, respectively), while the differences in the booster cushion or seat displacements relative to the car seat were small (2÷3 cm).

7. Recapitulation

Despite ongoing improvement in the passive safety systems in motor vehicles, older children, aged from 8 to 12 years, are still exposed to severe injuries in road accidents. Usually they are too big for being transported in safety seats provided with integral seat belts and too small for being fastened with seat belts intended for adults. The booster cushions or booster seats (without or with backrests, respectively), commonly used for children in these age brackets, improve the effectiveness of operation of the seat belt and simultaneously are relatively easy for use. In spite of this, many parents too often give up using a child restraint system of this kind. The research results presented here show important relations between the type of the child restraint system used and the observed loads of dummy's head and torso. They have confirmed that children should not be protected by mere use of standard seat belts intended for adults because in such a case the position of the belt strap in relation to child's body is very unfavourable as the seat belt may cause injuries to child's neck and abdomen in these conditions.

The risk of injury to the child in tests B, P, and F was assessed in publication [19]. Based on the loads of the head and torso of the P10 dummy, the risk of injury in tests B, P, and F was estimated at 74%, 12%, and 26%, respectively.

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