

# ANALYSIS OF THE FORCES DEVELOPING IN THE STRAPS OF THE BELTS THAT RESTRAIN A CHILD IN A SAFETY SEAT

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## Summary

The paper comprises the most important observations concerning the appropriate use of child car seats, with special attention being given to seat belt straps, which are among the critical elements of the child restraint system. The appropriate positioning and pre-tensioning of the child restraining straps and the most frequent faults in using the belts have been highlighted. Results of strength tests of belt straps of 25.4×1.56 mm and 38.6×1.23 mm cross-section (narrow belts and wide belts, respectively) have been presented. The time histories and distribution of forces in the shoulder and lap belts restraining a child with a mass of 15 kg were examined. Two types of child safety seats, referred to as "safety seat 1" and "safety seat 2", were used. A car crash was simulated by braking a measuring trolley from a velocity of 50–52 km with a deceleration of up to 28 g. The distribution of forces in the shoulder and hip belts of the harness restraining a test dummy was analysed. The force distribution was found to depend on the seat construction. The test results and graphs presented indicate a possibility of evaluating the effectiveness of child safety seats in the car collision phase.

**Keywords:** passive safety, child safety seats, seat belt straps

## 1. Introduction

Seat belts are the most effective known device intended to save vehicle occupants' life during a road accident. According to research carried out and information provided in many different publications, the use of seat belts reduces the number of deaths and severe

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bodily injuries to vehicle occupants by about 50% and about 25% if the victims occupy front or rear car seats, respectively [9]. Children should be transported in safety seats appropriate for child's age, body mass, and height.

Safety seats should be so installed that they should adequately serve their purpose, i.e. reduce to the minimum the risk of injuries during an accident. Numerous public campaigns, such as "The last escapade" or "Fasten your seat belt, turn your thinking on", are run to reduce such a risk. Alas, data available from the National Road Safety Council show that the effects of such endeavours cannot be deemed satisfactory. It still happens that a child safety seat is incorrectly selected and fitted in a vehicle and the seat belts are improperly fastened. As an example, results of an inspection carried out by the Municipal Headquarters of the State Fire Service and the Police in Rybnik in August 2014 showed that in 71 vehicles checked, child safety seats were properly fitted in only 7% of the total [4].

Most of the information available on the safe transporting of children in safety seats is focused on the construction, use, and fixing of the seats while rather little attention is paid to the seat belt straps proper. The straps are directly related to the possibility of injury because they tightly wrap the child's body; therefore, the values of the forces developing in them during a collision are particularly important.

In this article, the most frequent faults in using the belts have been discussed, especially those related to the appropriate positioning and pre-tensioning of the straps that restrain the child. The article comprises results of strength tests of the straps and time histories of the forces that developed in the straps in the simulated collision phase, during which the measuring trolley was braked from a velocity of 50–52 km/h to a stop with a deceleration of up to 28 g. Graphs have also been presented, which may be taken as a basis for the safety seat quality assessment in respect of the correctness of the distribution of forces in the shoulder and hip belts of the safety harness.

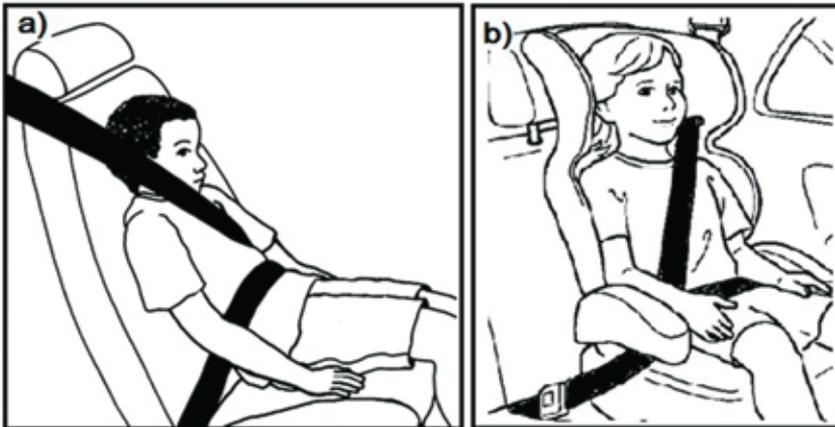
## **2. Pre-tensioning and positioning of seat belt straps**

Seat belts constitute a complex system consisting of many different components, such as belt straps, buckles, adjustment hardware, and anchorage parts. An important element of the system is a flexible strap, which is to restrain a child safely in the seat during normal ride and, especially, during an accident.

The instructions for installing a safety seat should describe not only the method of fixing the seat in a car but also the correct method of securing a child in the safety seat. The positioning of the belt strap should ensure the pressure exerted by the belt onto the child's body to be distributed as uniformly as possible over the entire belt strap surface that is in contact with the child's body. Any belt twists are unacceptable because they may affect the values of local loads and, in consequence, may cause more severe injuries to be incurred during an accident. This is particularly important during a collision of the car with another object, when inertia forces of high values are applied through the seat belts to the child's body. The problem of appropriate positioning of the belts restraining a child in the safety

seat has been presented in detail in paper [12], where it has been shown that the observed head and torso loads strongly depended on the type and positioning of the seat belt strap.

The harmful effect of seat belt operation, referred to as "Seat Belt Syndrome" [3], is connected with the fact that older children wear seat belts designed, basically, for adult passengers. Insufficient belt pre-tensioning may be a reason for the belt sliding down from the child's shoulder. It often happens that the shoulder portion of a seat belt is incorrectly positioned in the vicinity of the child's neck (Fig. 1a), which may cause injuries in the form of bruises and skin abrasions as well as blood extravasations in the area close to the clavicle. The lap portion of the seat belt should lie low on the hips. If it is placed higher and it constricts the child's abdomen, then it may cause injuries to the organs in the abdominal cavity in case of an accident [5]. These requirements have been laid down in UN ECE Regulation No. 44 [8], where a provision has been made that the straps of seat belts for children should not exert excessive pressure on the abdomen and crotch. The strap must remain on the pelvis and must not slide onto the abdomen in any conditions, inclusive of a collision or overturning of the car. The correct positioning of the shoulder portion of the seat belt is facilitated by appropriate shaping of the safety seat (if made in the form of a booster seat, i.e. where the child is restrained by a car seat belt, Fig. 1b).



**Fig. 1. a) The shoulder belt portion placed too close to the child's neck; b) Appropriately shaped booster seat, facilitating correct positioning of the seat belt**

The seat belt straps are flexible and can dissipate energy. The tighter the seat belt strap fits the child's body during normal ride, the lower loads would act on the child's body and the smaller movements of internal organs of the child would be in relation to the surrounding bone structures in case of a collision. However, the pre-tensioning of the seat belt should ensure not only safety but also adequate comfort to the child.

The BeSafe Company, a manufacturer of child safety seats, advises that the seat belt should be so tightly pre-tensioned that no more than two fingers should fit between

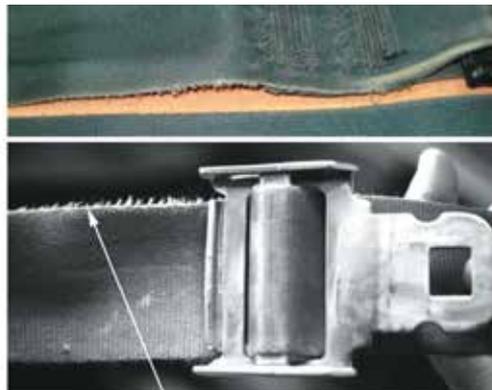
the child's body and the harness. The requirements set out by Maxi-Cosi are even more stringent, as this child seat manufacturer recommends that no more space than 1 cm should be left between the seat belt strap and the child's body, which corresponds to the possibility of putting only one finger into the gap. According to Britax, the safety harness should be tightened to such an extent that the "pinch test" could not be performed on the shoulder belt portion.

The seat belt strap operates in contact with rigid parts (buckles, adjustment hardware, and anchorage components), which, if improperly configured, may cause the breaking strength of the strap to be reduced and the strap to break during a car collision. Folds resulting from careless use of the belt (Fig. 2) may be a reason for the breaking of even a new strap; moreover, they may hinder free sliding of the strap when the seat belt is being fastened and thus make it difficult to position and pre-tighten the belt correctly.



**Fig. 2. Examples of folded seat belt straps [2]**

In new seat belt straps, the edges are hemmed to prevent them from fraying during use. If a strap is found to be frayed (Fig. 3), it should be replaced with a new one.



**Fig. 3. Examples of frayed edges of seat belt straps**

The straps may also be weakened by the impact of chemicals, improper temperature, or solar radiation. Therefore, strap samples are tested after being subjected to various treatment procedures, referred to as "conditioning", in order to make sure that their mechanical and performance characteristics are as expected. Within the conditioning, the strap samples are exposed to low and high temperatures, light, and water. The "conditioning" may also include abrasion carried out on various machines, where the strap remains in contact with the rigid parts of other system components. After the conditioning, the breaking strength of the straps is determined in static tests [7].

### 3. Strength testing of seat belt straps

Seat belt straps are made of polyester, polyamide, and polypropylene fibres. Sometimes the strap structure is stiffened by additional layers of transverse fibres.

The breaking strength of the strap is tested in compliance with the requirements of UN ECE Regulation No. 16 [7]. At the test, a strap specimen should be gripped between the clamps of a tensile-testing machine. The clamps should be so designed as to avoid strap breakage in their vicinity. The tensioning rate should be about 100 mm/min. The free length of the specimen between the clamps of the machine at the start of the test should be  $200 \text{ mm} \pm 40 \text{ mm}$ . When the test load reaches 980 daN, the strap width should be measured without stopping the machine; then, the tension should be further increased until the strap breaks, and the breaking load should be noted. The breaking load should not be less than 1 470 daN. The breaking load values measured for two specimens should not differ from each other by more than 10 % of the higher value of the load measured. The difference between the breaking strength of two specimens should not exceed 20 % of the higher breaking strength measured.

The results of measurements of the breaking strength of seat belt straps have been briefly presented below; for more details, see publication [1]. The quasi-static axial tensioning of the strap specimens was carried out with the use of a tensile-testing machine Instron 8802 (Fig. 4).

The tests were carried out on three narrow and five wide seat belt strap samples, with  $25.4 \times 1.56 \text{ mm}$  and  $38.6 \times 1.23 \text{ mm}$  cross-sections, respectively. The test specimens were subjected to quasi-static axial tensioning, which was increased until they broke. The piston of the tensile-testing machine moved at a rate of 100 mm/min. During the tests, changes in the measuring length between two marks made on each specimen were recorded and force-displacement and stress-strain curves were plotted on these grounds.



Fig. 4. Method of gripping seat belt strap specimens on the measuring stand built on an Instron 8802 tensile-testing machine

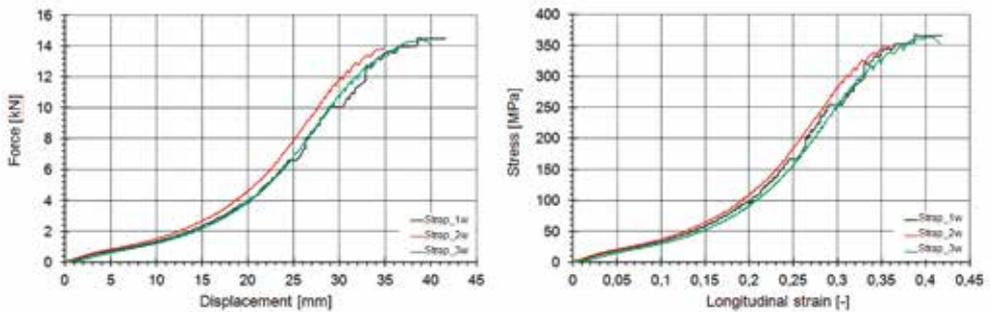


Fig. 5. Graphs representing tensile test results obtained for the narrow belt straps

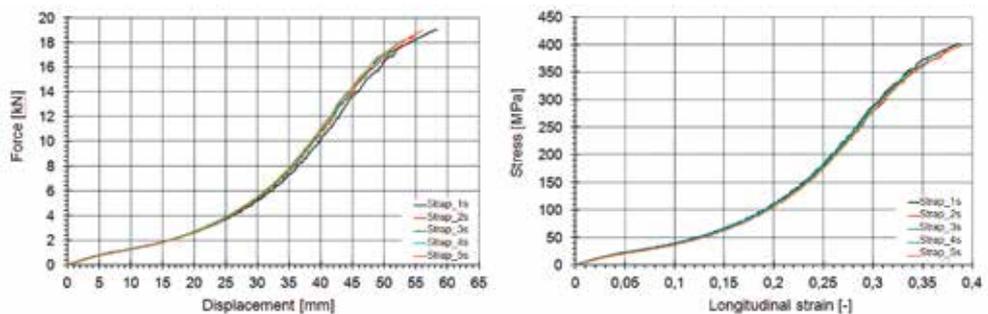


Fig. 6. Graphs representing tensile test results obtained for the wide belt straps

The characteristic curves presented in Fig. 5 (for narrow belt straps) and Fig. 6 (for wide belt straps) show that the stiffness values of the straps under test at low force and stress values were lower by almost a half than those of the straps at a load equal to 50% of the ultimate strength (breaking load) of the straps.

The average values of the measurement results obtained for all the belt straps under test have been presented in Table 1.

**Table 1. Strength test results**

<b>Average values of the quantities measured</b>	<b>Narrow straps</b>	<b>Wide straps</b>
Maximum (breaking) force	1 425 daN	1 853 daN
Tensile strength	356.9 MPa	390.7 MPa
Breaking strain*	38.9%	37.6%

\* Relative elongation of the measuring length of the specimen, in [%]

Pursuant to UN ECE Regulation No. 16, the breaking load of the strap shall be not less than 1 470 daN. According to Table 1, this requirement was met by all the wide strap specimens under test. Conversely, the average value of the breaking force determined for the narrow straps, equal to 1 425 daN, was somewhat lower than the minimum required by UN ECE Regulation No. 16 (it made 97% of the required minimum breaking force).

## 4. Examination of the forces in seat belt straps

The objective of this work was to determine the characteristic curves that would visualize changes in the forces developing in seat belt straps under the impact of the decelerations of a measuring trolley in the collision phase when the seat belts are used to restrain a child dummy in a child safety seat during a crash test.

The seat belt forces were measured on a crash-test stand AB-554 at the Automotive Industry Institute (PIMOT) in Warsaw.

During the tests, a dummy representing a child of 15 kg mass was placed in a child safety seat, which was secured to a vehicle seat with the use of ISOFIX attachments and tightened with a force of 25 daN (pursuant to UN ECE Regulation No. 44).

A general view of the measuring trolley prepared for tests has been presented in Fig. 7.



**Fig. 7. General view of the child dummy placed in a child safety seat, which was secured to a vehicle seat rigidly mounted on the measuring trolley**

In general, three tests were carried out. At the first test, the child dummy was placed in safety seat 1. The second test was carried out with safety seat 2 being used. The third test was a repetition of the second test, but it was preceded by removal of safety seat 2 and its reinstallation on the vehicle seat, thanks to which the impact of the safety seat fixing operation could be examined.

Safety seat 1 was a typical low-priced child car seat while safety seat 2 was one of the more expensive models available in the market. The safety seats under test were characterized by different stiffness of their structures (especially the lateral stiffness), depending on the shape of the bare plastic seat shell. In safety seat 1, the seat shell cross-section was considerably weakened at a place where stress concentration may occur, due to the necessity of making appropriate fairleads (slots) for cross belts. The structure of safety seat 2 was much stiffer, e.g. it was provided with a reinforcing flat steel bar in the upper part of the seat shell.

The measuring trolley with a rear car seat rigidly mounted on it, having been brought up to a speed of 52 km/h (at tests 1 and 2) or 50 km/h (test 3), was rapidly braked to a standstill with a deceleration of up to 28 g (where g is the acceleration of gravity). The course of all the tests was recorded with the use of a high-speed camera, with the time histories of the measuring trolley deceleration being simultaneously recorded. Thanks to the use of time markers, the video record frames were selected that showed the instantaneous positions of the safety seat and the dummy at the instants when the largest displacements were recorded. The maximum dummy's displacements recorded during the rapid braking phase have been presented in Fig. 8.



**Fig. 8. Maximum dummy's displacements during the tests (video record frames): test 1 – safety seat 1; tests 2 and 3 – safety seat 2**

The displacement of safety seat 1 (test 1) was markedly bigger than that of safety seat 2 (tests 2 and 3) in spite of similar safety seat fastening systems (with ISOFIX attachments being used at each test) and identical input parameters of the experiment. This means that the maximum displacement of a child safety seat with a dummy in relation to the car seat chiefly depends on the construction of the safety seat under consideration. This finding is confirmed by results of tests 2 and 3, where the maximum displacements of the same safety seat were practically identical to each other.

A more thorough analysis of the measurement results showed that the maximum deceleration of the trolley and the maximum displacement of the dummy did not take place at the same time. For safety seat 1 (test 1, Fig. 8), the maximum displacement of the dummy was delayed by about 10 ms in relation to the maximum deceleration of the measuring trolley. For safety seat 2, the delays were longer, equal to about 40 ms and about 30 ms at tests 2 and 3, respectively (Fig. 8). These results indicate the following regularity: the more rigidly a safety seat is fastened to a car seat the longer delay occurs in the maximum dummy's displacement.



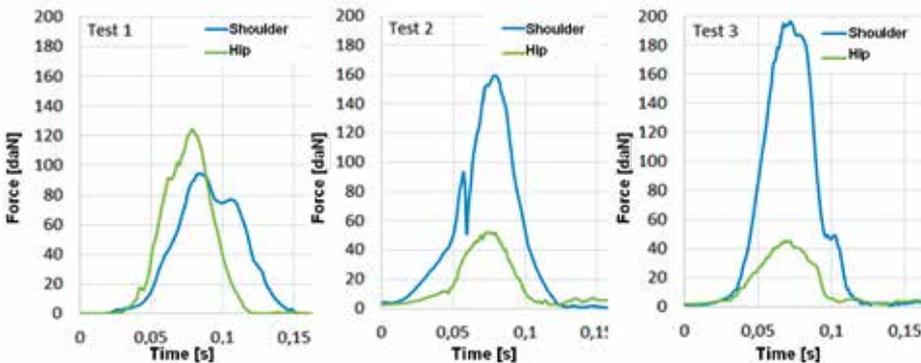
**Fig. 9. View of the load cells used to measure the forces developing in the shoulder and hip portions of the safety harness securing the test dummy in the child safety seat**

During the tests, the forces developing in the upper (shoulder) and the lower (hip) portions of the strap of the chest belt were recorded. The location of the load cells used for this purpose has been shown in Fig. 9.

The method of tensioning the integrated safety harness to set the gap between the child and the safety harness straps as required was different for the two safety seats under test. In safety seat 1, the harness was pre-tensioned by pulling the upper (shoulder) belts while the lower (hip) belts were pulled to pre-tension the harness in safety seat 2. Apart from this, the harness of safety seat 2 was provided with a system to adjust automatically the position of the lower belt in the area close to the child's crotch (the mechanism operated the belt part that was directly connected with the belt buckle with a latch), while no such a system was provided in the harness of safety seat 1.

The forces in the harness straps restraining the dummy in the safety seat come from the inertia force that is generated when the measuring trolley is braked. The inertia force is applied longitudinally (along the X axis, in the direction of vehicle drive). The inertia force is chiefly balanced by the forces in the safety harness straps (the friction between the dummy and the seat bottom is of less importance).

The time histories of the forces in the shoulder and hip portions of the harness restraining the dummy in the safety seat have been presented in Fig. 10. All the graphs have been plotted in the same scale to facilitate a comparative analysis.



**Fig. 10. Forces in the shoulder and hip portions of the harness restraining the dummy in the safety seat: test 1 - safety seat 1; tests 2 and 3 - safety seat 2**

The distribution of forces in the strap of the harness restraining the dummy in the safety seat differs depending on the safety seat model. Based on the video record frames shown in Fig. 8, the maximum force in the shoulder portion of the harness of safety seat 1 may be estimated to be lower than that recorded for safety seat 2 because of higher flexibility of the safety seat 1 fastening system (bigger displacement of this seat). This estimation is confirmed by the graphs shown in Fig. 10 and the data given in Table 2.

**Table 2. Maximum values of the forces in the shoulder and hip portions of the harness restraining the dummy in the safety seat**

	<b>Test 1 (safety seat 1)</b>	<b>Test 2 (safety seat 2)</b>	<b>Test 3 (safety seat 2)</b>
Shoulder belt	94.44 daN	157.37 daN	196.53 daN
Hip belt	124.33 daN	49.76 daN	43.5 daN

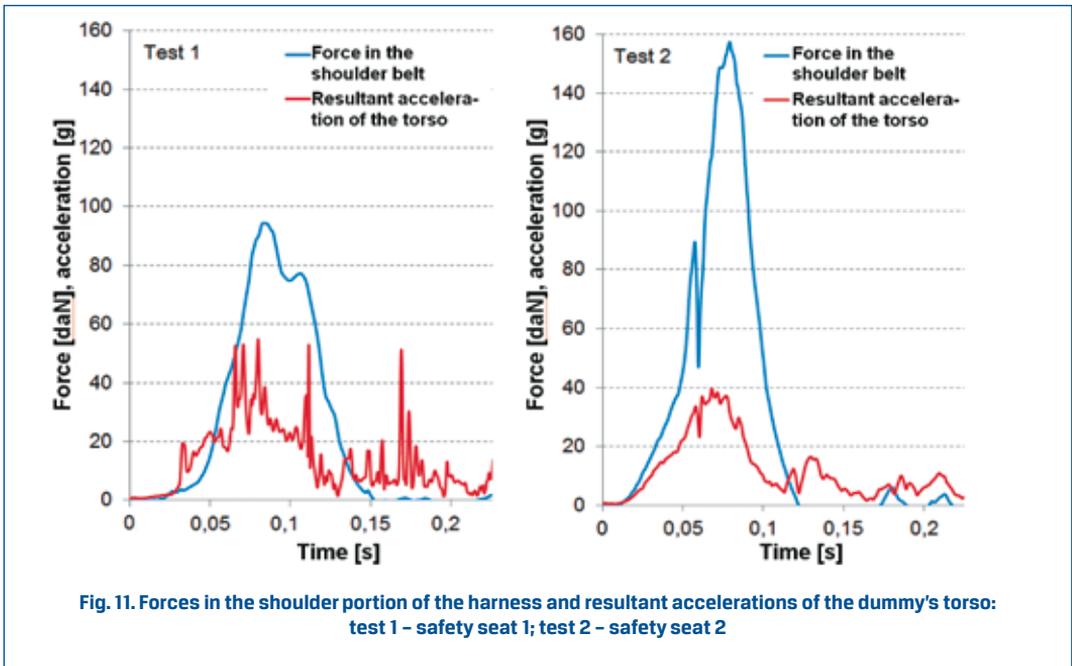
The maximum value of the force in the shoulder portion of the harness of safety seat 1 was somewhat higher than 90 daN as against those of safety seat 2, equal to about 158 daN and about 196 daN, i.e. the forces for the latter safety seat were much higher (at the same input loads). An opposite trend can be noticed in the maximum values of the forces developing in the hip belt. Hence, a question arises, which solution is more favourable for the children transported in such safety seats. It is worth noticing that the values of the forces developing in the shoulder and hip portions of the harness of safety seat 1 were comparable with each other and, simultaneously, they did not reach the level of the maximum force that developed in the shoulder portion of the harness of safety seat 2. This means that the risk of injury to the child riding in safety seat 1 may be considered lower. Another disadvantage of safety seat 2 was the fact that the forces developing in the shoulder and hip portions of the harness of this safety seat significantly differed from each other: the maximum values of the forces in the shoulder belts of safety seat 2 were 3 to 5 times as high as those in the hip portion of this harness.

The highest values of the forces recorded did not exceed a level of 200 daN. When compared with the results of testing the seat belt straps as presented in Table 1, this makes about 14% of the average values of the maximum forces that can be transmitted by the narrow belt straps and about 11% of the average values of the maximum forces that can be transmitted by the wide belt straps under test. This translates into a finding that a breakage of the straps of the harnesses under test is rather unlikely.

During the tests, accelerations (actually, deceleration for the component measured in the X direction) of the dummy's torso were measured in three mutually perpendicular directions of axes X, Y, and Z. The coordinate system XYZ was oriented as follows: axis X coincided with the direction of motion of the measuring trolley (horizontal); axis Y was perpendicular to the direction of motion of the measuring trolley (horizontal, too); axis Z was perpendicular to the XY plane (i.e. it was vertical). The value of the resultant acceleration was determined as a square root of the sum of squares of the values of accelerations along axes X, Y, and Z.

As a rule, time histories of dummy's torso acceleration are measured at typical tests of child safety seats. The carrying out of such measurements is easy because, in most cases, test dummies are provided as standard with the necessary sensors. On the other hand, the test stand must be specially prepared for the forces in safety belts to be measured. A question arises, whether the force developing in the shoulder belt portion can be estimated from a dummy's torso acceleration vs. time curve having been recorded.

Time histories of the force in the shoulder portion of the harness restraining the dummy in the safety seat and the resultant dummy's torso acceleration have been presented in Fig. 11. Test 1 and test 2 were carried out for safety seats 1 and 2, respectively. The recorded time histories of the dummy's torso acceleration at both tests were similar to each other in both qualitative and quantitative terms; in particular, the maximum acceleration value was about 40 g and it occurred within the period from 0.05 s to 0.1 s.



As it can be seen in the graphs presented in Fig. 11, the highest values of the force in the shoulder belt and the highest values of the resultant acceleration of the dummy's torso occurred in basically the same period, although the force in the shoulder belt was delayed by about 0.03 s in relation to the resultant acceleration of the dummy's torso. However, the maximum values of the forces developing in the shoulder belts of the harnesses of both safety seats significantly differed from each other. This means that the value of the force developing in the shoulder belt cannot be reliably estimated from time histories of the accelerations recorded to occur in the dummy's torso.

Fig. 11 also shows that at the tests carried out, the fastening system of safety seat 1 (test 1) performed better than that of safety seat 2 (test 2) did, because at similar maximum values of the resultant accelerations of the dummy's torso (about 40 g), the force in the shoulder portion of the harness of safety seat 1 was lower by about a half than that recorded for safety seat 2.

## 5. Conclusions

1. The flexible straps are an important component of the harness of a child restraint system as they have a significant impact on the performance characteristics of such a system. The positioning of the belt strap should ensure the pressure exerted by the belt onto the child's body to be distributed as uniformly as possible over the entire belt strap surface that is in contact with the child's body.
2. The stiffness values of the straps under test at low force and stress values are lower by almost a half than those of the straps at a load equal to 50% of the ultimate strength (breaking load) of the straps.
3. When similar safety seat fastening systems (ISOFIX) are used and identical input loads are applied, the maximum displacement of a child safety seat with a dummy in relation to the car seat chiefly depends on the construction of the safety seat under consideration.
4. The maximum deceleration of the measuring trolley occurs before the maximum displacement of the dummy. In the cases under analysis, this time difference was about 10 ms for safety seat 1 and about 30–40 ms for safety seat 2 (see Fig. 8).
5. The distribution of forces in the strap of the harness restraining the dummy in the safety seat varies depending on the safety seat model in spite of identical input loads. The information concerning this issue may be an element of assessment of the performance of child restraint systems in the collision phase.
6. The value of the force developing in the shoulder belt of the safety harness cannot be reliably estimated from time histories of the accelerations recorded to occur in the dummy's torso.

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## References

- [1] BOGUSZ P.: *Badania wąskich i szerokich pasów bezpieczeństwa fotelika dziecięcego (Testing of narrow and wide safety belts of a child car seat)*. Military University of Technology, Department of Mechanics and Applied Computer Science, not published, 2014.
- [2] BREADY J. E., NORDHAGEN R. P., KENT R. W.: *Seat Belt Survey: Identification and Assessment of Noncollision Markings*. SAE Paper 1999-01-0441.
- [3] DOYLE J. J. JR., LEVITT S. D.: *Evaluating the Effectiveness of Child Safety Seats and Seat Belts in Protecting Children from Injury*. August 2006, <http://www.nber.org/papers/w12519>.
- [4] [http://fotelik.info/pl/news/inspekcje\\_fotelikow\\_2014\\_w\\_rybniku\\_relacja,521.html](http://fotelik.info/pl/news/inspekcje_fotelikow_2014_w_rybniku_relacja,521.html).

- [5] ŁABĘCKA M., ŻABA CZ., LORKIEWICZ-MUSZYŃSKA D., ŚWIDERSKI P., MULARSKI A., KOŁOWSKI J.: *Obrażenia śmiertelne narządów szyi spowodowane zapiętymi pasami bezpieczeństwa (Fatal injuries of organs situated in the neck caused by fastened seat belts)*. Archiwum Medycyny Sądowej i Kryminologii, 2011, LXI, Case Reports 2011, pp. 170–175.
- [6] UN ECE Regulation No. 129: *Uniform provisions concerning the approval of enhanced Child Restraint Systems used on board of motor vehicles (ECRS)*.
- [7] UN ECE Regulation No. 16: *Uniform provisions concerning the approval of: I. Safety-belts, restraint systems, child restraint systems and ISOFIX child restraint systems for occupants of power-driven vehicles. II. Vehicles equipped with safety-belts, safety-belt reminders, restraint systems, child restraint systems and ISOFIX child restraint systems and i-Size child restraint systems*.
- [8] UN ECE Regulation No. 44: *Uniform provisions concerning the approval of restraining devices for child occupants of power-driven vehicles ("child restraint system")*.
- [9] *Seat-belts and child restraints: a road safety manual for decision-makers and practitioners*. London, FIA Foundation for the Automobile and Society, 2009.
- [10] SZMYTKOWSKA K., LEDKIEWICZ G., ORNET M., PIESIEWICZ A.: *Pasy bezpieczeństwa – ochrona czy zagrożenie? (Safety belts: protection or threat?)*. [http://www.darpomocy.pl/dok/pasy\\_bezpieczenstwa.pdf](http://www.darpomocy.pl/dok/pasy_bezpieczenstwa.pdf)
- [11] WICHER J.: *Niekolizyjne ślady użytkowania pasów bezpieczeństwa (Non-collision marks of the usage of safety belts)*. Rzeczoznawca Samochodowy, No. 11/2007 (145), pp. 18–23.
- [12] ŻUCHOWSKI A.: *Wpływ rodzaju urządzenia ochronnego na kinematykę i obciążenia dziecka w samochodzie podczas zderzenia czołowego (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)*. The Archives of Automotive Engineering – Archiwum Motoryzacji, 2013, 61(3), pp. 65–79.
- [13] ŻUCHOWSKI A., WICHER J.: *Wpływ wstępnego napięcia pasów bezpieczeństwa na obciążenia pasażerów na tylnych siedzeniach podczas zderzenia czołowego (Influence of the pre-tightening of seat belts on the loads acting on rear seat occupants during a frontal collision)*. The Archives of Automotive Engineering – Archiwum Motoryzacji, 2/2013, pp. 209–226.