ANALYSIS OF VERTICAL VIBRATIONS AFFECTING A CHILD TRANSPORTED IN A CHILD SEAT DURING A CAR PASSING OVER THE RELEASE SPEED BUMP

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Abstract

The article presents the results of research on the assessment of vibrational comfort of children carried in child seats. The study analyzes the effect of the child's mass and the speed of the car traversing the speed bump on the level of vibration to which the passenger (child) transported in the child seat mounted on the rear seat of the car is exposed. The tested car seats were installed in a passenger car using the ISOfix base. During the tests, the acceleration values were the acceleration of the seat of child seat, the backrest of the child seat, the rear seat of the car and the child seat ISOfix base were measured. As part of the research, the car was being traversed the speed bump with different speeds and different values of additional mass simulating that of a child. The analysis of test results allowed determination the magnitude of vibrations generated during car traverse the speed bump. Based on the results obtained, the level of vibrational comfort of a child trip in a child seat was assessed. Research has shown that the highest acceleration values occur on the basis of the ISOfix used to attach car child seats.

Keywords: vehicle safety; vibrations; child seat; vibrating comfort

1. Introduction

With the development of the economy and the manufacturing process of cars, the number of vehicles is constantly growing worldwide. The manufactured cars have more and more sensors supervising the driver's operation, improving safety or facilitating the use of the car [3, 6, 22]. The vast majority of the society uses the car every day when commuting to work, school or shopping. A positive aspect related to the progress of the car manufacturing is the increase in the standard of living of society. There are also negative aspects such as the increase in traffic, the lack of parking spaces and the increased number of road accidents [2]. Despite this, modern society is increasingly choosing to transport by private car instead of public transport. Travelling by car we are exposed to many dangers including to health harmful vibrations [1, 10, 16].

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Comfort is a relative concept for every human being [12, 15]. For one person, the feeling of comfort in the car will be provided by a comfortable soft car seat, and for another, the feeling of comfort will be ensured by a properly selected car suspension that will damp vibrations generated by the uneven road surface [12]. The driver and passengers of the car can assess the vibration comfort based on the accelerations acting on them. These accelerations depend on the amplitude and frequency of the vibrations. Accelerations up to 12 Hz affect all human organs, while low frequency cycles from 4 Hz to 6 Hz can cause muscle fatigue or local back pain [12, 13, 17]. Exposure of the driver and passengers to this type of vibration can cause numerous pathological symptoms from the digestive system, lumbosacral and cervical spine pains, occurrence of kyphosis and lordosis of the spine, joint and muscle pains, labyrinth symptoms (motion sickness), headaches. They can also contribute to limitation of mobility, vision, free communication, weakening of memory processes and perception [12, 13, 23].

Vibrations can pose a threat to humans and shorten the life of the car. Vibrations are transmitted through the steering wheel, seats car, all kinds of handles and the floor of the car. Driving safety and comfort are affected by factors such as the type and value of vibrations transmitted from the road to the vehicle body. This is due to the technical condition of the vehicle and road [12, 13, 15]. The adverse impact of mechanical vibrations on the human body has been the subject of systematic researches and observations for many years. Such studies were mostly conducted on adults. However, the negative effect of mechanical vibrations on children remains to this day unknown. The transmitted vibrations have a major impact on children's travel comfort [12, 14, 17]. Nowadays, small passengers are transported in car child seats, much oftener than a few years ago. The safest way to transport a child in a car is a car child seat. The child seats should be adjusted to the child's mass and anthropometric dimensions [12, 19, 21]. The dimensions of the child seats are very important because young children grow rapidly and their anthropometric dimensions change. Therefore, when using car child seats, you may meet problems such as too narrow a headrest or too narrow seat in the child seat. Unfortunately, the child seat classification system only applies to the child's age and mass, not to his anthropometric dimensions [12, 13, 19].

Most studies on the child seats so far has been focused on improving crash safety, which is their main function [4, 10, 19]. According to the European safety certificate ECE R44-04, a child seat must be adapted to the child's size and mass [12, 20]. However, the location of the child seat is not legally specified. The most common problem with child seats is its correct selection and correct installation in the car [4, 11, 12]. Before buying a child seat, you should check whether it will fit the seat of the car in which it will be installed. The check is also needed whether the car seat has the correct length of seat and back, whether the car has ISOfix fasteners and whether the inertial three-point car belts have the right length [4, 12]. You will find all the information you need to buy your child seat in its user guide. There are three basic ways to install a car seat in a car. The first is installation using standard seat belts, the second is installation with the ISOfix system and the third is using the ISOfix base [4, 9, 12].

When it turned out that the installation of a car seat equipped with the ISOfix system is much easier than when mounting using standard seat belts, the seat manufacturers proposed that their installation in cars should be carried out using an appropriate base [1, 9].

The base of the seat is an intermediate element, which is installed permanently in the place where the child seat should be in the car. The base is attached with ISOfix connectors and is additionally stabilized using an adjustable support [1, 9, 14]. This solution also allows you to take some energy in the event of a collision or sudden braking of the car. The child seat can be easily removed from the base and quickly attached if it needs to be removed from the car. The advantage of using the base is the fact that you can use it without any problems for many years using different sizes of car seats, provided that the base and the seat were manufactured by the same manufacturer [9, 12].

2. Methods for assessing vibrational comfort

The first attempts to determine vibrational comfort were made by German researchers Helberg and Sperling. They developed the formula of the W_z (1) indicator, which was used for many years in international standards [7, 13, 15].

$$W_z = 2{,}7 \cdot (a^3 \cdot f^3 \cdot F(f))^{0.1} \tag{1}$$

where:

a – peak acceleration values, cm/s^2,

f – frequency of vibrations, Hz,

$F(f)$ – mass index, taking into account the sensitivity of the human body to specific frequency bands.

In 1956, Sperling and Betzhold improved the existing formula of the W_z (1) indicator. Then they presented the result of their work with the formula (2) [7, 13, 15].

$$W_z = \left[\frac{1}{T}\int_0^T (B(f) \cdot a(t))^2 dt\right]^{0.15} \tag{2}$$

where:

$B(f)$ – amendments that take into account the increased sensitivity of the human body to specific frequency bands;

$a(t)$ – peak acceleration values measured at floor level, cm/s^2,

f – vibration frequency, Hz.

The basic assessment of the impact of vibration on vibrational comfort while driving car is the effective value of accelerations (rms) acting in the vertical direction (3). For accelerations $a(t)$ registered as occurring stationary implementation of the stochastic process, effective value of accelerations (rms) is most often an indicator of the assessment of vibrational comfort [7, 13, 15].

$$\mathrm{r.m.s} = \left[\frac{1}{T}\int_0^T a^2(t)dt\right]^{\frac{1}{2}} \tag{3}$$

where:

$a(t)$ – recorded as a function of time t, the value of acceleration acting in the vertical direction, m/s^2

T – segment of the duration of the measurement, s.

In addition, the VDV (Vibration Dose Value) indicator (4) is also used to assess vibrational comfort. This indicator was specially developed for vibration analysis of the whole human body. The rms and VDS values are not correlated with each other because they perceive the amplitudes of the measured acceleration in different ways. Both indicators do not estimate the impact of a temporary increase in vibration [13, 19].

$$VDV = \left[\int_0^T a^4(t)dt\right]^{\frac{1}{4}} \tag{4}$$

where:

$a(t)$ – the frequency weighted acceleration as a function of in time, m/s^2

T – is the duration of measurement in (s).

In order to correctly assess the instantaneous vibration increase. Used the vibration comfort index rmq (5) developed by M.J. Griffin and featured by British Standard BS 6841 [8, 13].

$$rmq = \frac{1}{T}\int_0^T a^4(t)dt^{\frac{1}{4}} \tag{5}$$

where:

$a(t)$ – the frequency weighted acceleration as a function of in time, m/s^2

T – is the duration of measurement in (s).

The efficiency of damping vibrations transmitted from the car body to the car seat can be expressed using the $SEAT$ (Seat Effective Amplitude Transmissibility) indicator. This dimensionless factor depends on the vibration spectrum, vibration permeability through the chair material, and on the magnitude and frequency of accelerations originating from the road Surface [5, 18]. This demonstrates the ability of the seat to dampen vibrations in the vehicle in such a way as to protect the driver and passengers from excessive vibration. The $SEAT$ (6) value is used to describe the vibration isolation of the car seat [13].

$$SEAT = \frac{V.D.V_F}{V.D.V_P} \tag{6}$$

Where:

$V.D.V_F$ – Vibration Dose Value determined for the car seat

$V.D.V_P$ – Vibration Dose Value determined for the surface to which the car seat is attached

3. Test stand

During the tests, vertical acceleration values in the zones of the seat child seat, the backrest of the child seat, the rear seat of the car and the child seat ISOfix base used to attach the child seat were recorded. Two child seats were used for experimental research: one signed as "A" for transporting children up to 13 kg and the other one "B" signed as for transporting children up to 17.5 kg.

The child seats mounted in the car using the ISOfix base were used during the tests. The "A" car child seat is designed for transporting children up to 13 kg and has four stars in the ADAC test. The curb mass of the car seat equals 2.5 kg, which makes it much lighter than the "B" seat, which mass is of 4 kg. The child seats were forward-facing during testing. The child seats were made of is EPP (Expanded polypropylene), which material looks like foam polystyrene but is not so stiff and brittle as the latter. This material is not deformed even at high loads arising during a collision. The "B" seat is a seat in the (67-105) cm category and is intended for transporting children up to 17.5 kg and up size to 105 cm in accordance with the new approval I-Size – ECE R-129. This child seat can be installed in line with and against the direction of driving. The ISOfix base shown in Figure 1 was used to attach both the "A" car child seat and the "B" one. The base has been directly connected to the tested car's ISOfix system, and a sound signal indicates its correct installation. The tested child seats are shown in Figure 2.

a) b)

Fig. 1. View of base ISOfix used: a) base with unfolded stabilizing support, b) base with a complex stabilizing support

a) b)

Fig. 2. View of tested car child seats: a) child seat for transporting children up to 17.5 kg - "B", b) child seat for transporting children up to 13 kg - "A"

4. Test research

During the tests, the car child seats were loaded with a mass corresponding to 10 kg mass child and 15 kg mass child. The tests were carried out on a road with dry asphalt pavement, on which the PW-60 release threshold was located. During the tests, a passenger test car with child seats installed, drive the speed bump at 20 km/h, 30 km/h and 40 km/h. The vehicle speed was kept constant throughout the tests with an accuracy of /-2 km/h. A compact C-segment passenger car was used for testing. The tested car seats were mounted on the rear seat, behind the driver's seat. During the tests, the measuring signals (vertical accelerations) were recorded by means of the constructed measuring track schematically shown in Figure 3.

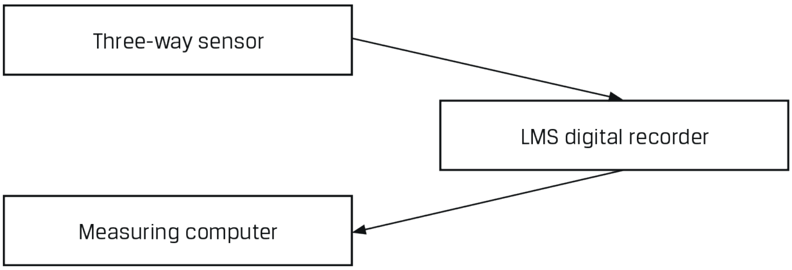

Fig. 3. Block diagram of the measurement system

In the conducted tests, the measured values were accelerations: car rear seats, seats and backrests of the tested child seats and the ISOfix base, which were measured using four three-directional acceleration sensors (Table 1).

Tab. 1. Basic technical parameters of three-directional acceleration sensors [23]

Parameters	Values
Maximum measuring range (g)	±10
Frequency band (Hz)	0,5÷1000
Resonance frequency (Hz)	≥ 27000

On the seat and back of the child seats and on the seat of the rear car seat, the sensors were mounted using semi-flexible measuring discs (Figure 4), while on the ISOfix base the sensor was attached directly to its base (Figure 5). The sensors are equipped with ceramic measuring elements and a titanium housing protecting them against mechanical damage. The LMS SCADAS Recorder digital recorder model SCR02 enables automatic operation after prior setting of the measurement parameters. Data were registered using a measuring computer.

a) b)

Fig. 4. Location and mounting method of three-directional acceleration sensors on the seat and backrest of a child seat: a) child seat for transporting children up to 13 kg - "A", b) child seat for transporting children up to 17.5 kg - "B"

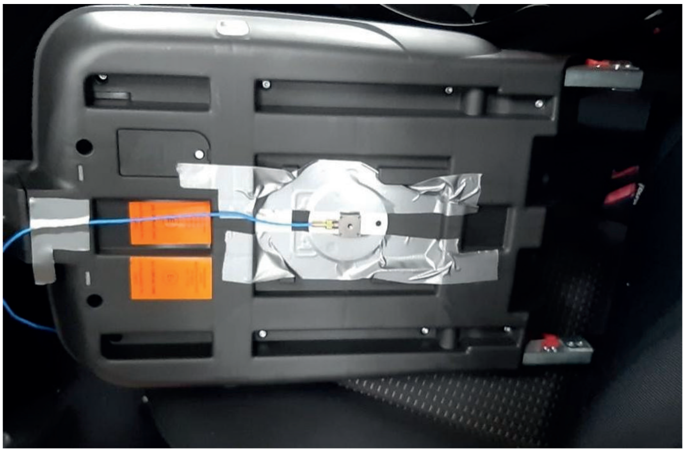

Fig. 5. Location and method of mounting the three-directional acceleration sensor based on ISOfix

The r.m.s. (3), V.D.V (4), r.m.q (5) and SEAT (6) factors were used to assess the vibrational comfort of a child seats. The r.m.s. coefficient is the basic method for assessing vibrational comfort. Table 2 shows the limits of vibration discomfort according to the assessment of r.m.s (3). The V.D.V coefficient is used for vibration analysis of the whole human body. Both r.m.s and V.D.V indicators do not estimate the impact of momentary vibrations during the entire journey of a passenger car. Therefore, the r.m.q coefficient was used to assess the vibrational comfort, which is used to estimate correctly the instantaneous vibrations. The SEAT indicator used allows assessing the vibrating comfort of a child seat in terms of vibration isolation of vibrations transmitted from the ISOfix base to the seat of a child seat.

Tab. 2. The level of vibration discomfort for r.m.s [12, 13, 15]

Effective acceleration r.m.s (m/s^2)	Discomfort level
$<$ 0.315	no discomfort
0.315 – 0.63	little discomfort
0.5 – 1	quite uncomfortable
0.8 – 1.6	uncomfortable
1.25 – 2.5	very uncomfortable
$>$2.5	extremely uncomfortable

5. Results

The results of the measurements carried out were used to determine the time course of vertical vibration acceleration and the value of r.m.s, V.D.V and r.m.q indicators used to assess vibration comfort. Exemplary time series of accelerations of vertical vibrations registered on: seat of child seat, rear seat of the car and on the basis of the base ISOfix, are presented in Figures 6 to 11. Recorded waveforms are hardly readable and difficult to analyze. Based on them, only some general conclusions were made. The maximum acceleration values recorded on the seat of the "A" car seat reach up to 2.86 m/s^2 at a driving car speed of 20 km/h and up to 4.97 m/s^2 at adriving car speed of 30 km/h. Accelerations registered on the seat of the "B" car seat are lower by 60% and 70%, respectively.

The increase in load on the tested child seats caused a decrease in the maximum accelerations registered on their seats. For the "A" child seat at a driving speed of 30 km/h, the acceleration of vertical vibrations recorded on seat of child seat reached 4.97 m/s^2. An increase in the load of this car seat by 5 kg caused a significant decrease of over 70% in the value of accelerations registered on the seat of the child seat. For the "B" child seat, the increase in the mass from 10 kg to 15 kg at a driving speed of 30 km/h also caused a decrease in the maximum acceleration values, but in this case it was only 1%.

The highest acceleration values were recorded on the ISOfix base used to attach car child seats. The courses of these accelerations differ significantly in terms of quantity and quality from the accelerations recorded on the seat of child seat and the rear seat. When driving at a speed of 30 km/h, the maximum values of vertical acceleration were registered on the basis of the ISOfix base fixing the "A" child seat or the "B" child seat and they were respectively 6.4 m/s^2 and 6.15 m/s^2.

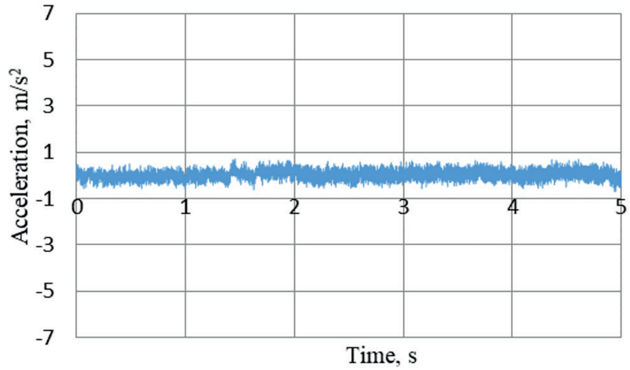

Fig. 6. Effective values of accelerations registered on the rear seat of the car, during driving car through the deceleration speed bump at a speed of 20 km/h, seat charged of mass 10 kg

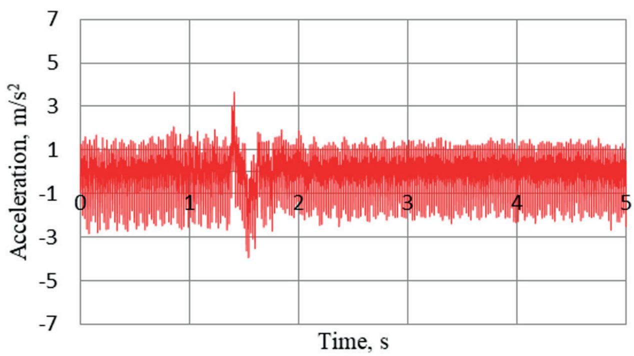

Fig. 7. Effective values of accelerations registered on the basis of ISOfix, during driving car through the deceleration speed bump at a speed of 20 km/h and charged of mass 10 kg on seat of "A" car child seat

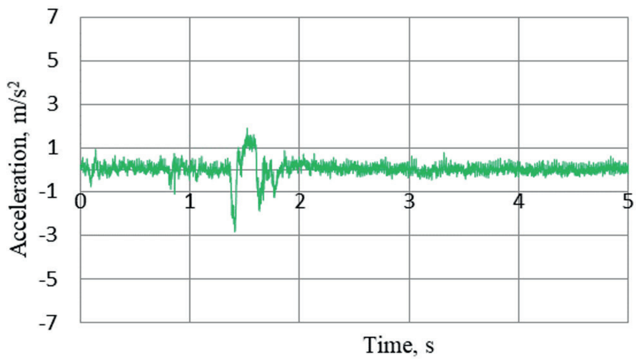

Fig. 8. Effective values of accelerations registered on the seat of the "A" car child seat, during driving car through the deceleration speed bump at a speed of 20 km/h, child seat charged of mass 10 kg

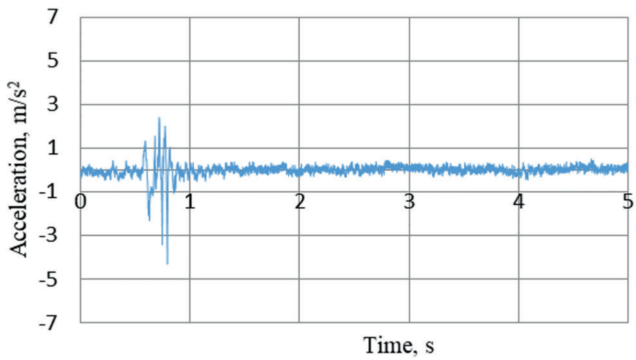

Fig. 9. Effective values of accelerations registered on the rear seat of the car, during driving car through the deceleration speed bump at a speed of 40 km/h, seat charged of mass 10 kg

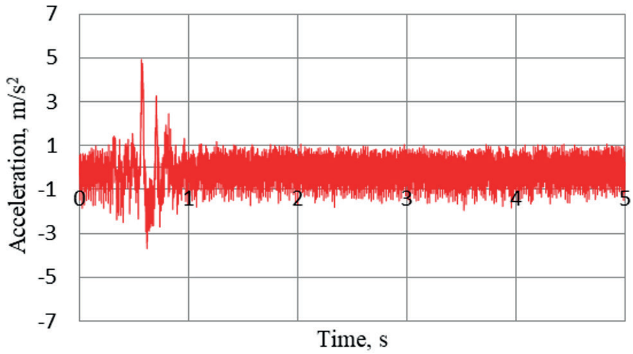

Fig. 10. Effective values of accelerations registered on the basis of ISOfix, during driving car through the deceleration speed bump at a speed of 40 km/h and charged of mass 10 kg on seat of "A" car child seat

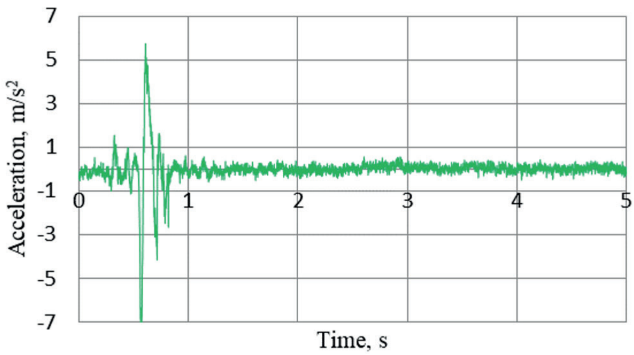

Fig. 11. Effective values of accelerations registered on the seat of the "A" car child seat, during driving car through the deceleration speed bump at a speed of 40 km/h, child seat charged of mass 10 kg

Table 3 presents the results of the vibration comfort assessment based on the indicators r.m.s, V.D.V and r.m.q. When assessing the vibration comfort using the r.m.s indicator, it was noticed that the accelerations registered during the tests may cause a slight discomfort in the child related during driving car through the deceleration speed bump. By far the highest values of the r.m.s index were recorded on the ISOfix base used to attach car child seats.

Tab. 3. Results of the vibrational comfort assessment

Mass. kg	Driving car speed. km/h	Vivibration comfort indicators	Car child seat "A"				Car child seat "B"			
			Location of the acceleration sensor							
			Seat rear car	Base Isofix	Seat of child seat	Backrest of child seat	Seat rear car	Base Isofix	Seat of child seat	Backrest of child seat
10	20	rms	0.207	0.747	0.365	0.260	0.162	1.537	0.191	0.281
		vdv	0.416	1.700	1.110	0.620	0.332	3.430	0.401	0.617
		rqm	0.278	1.137	0.742	0.415	0.222	2.294	0.268	0.412
	30	rms	0.155	0.660	0.418	0.689	0.213	1.546	0.226	0.330
		vdv	0.308	1.489	1.661	1.550	0.619	3.441	0.501	0.886
		rqm	0.206	0.995	1.111	1.037	0.414	2.301	0.335	0.592
	40	rms	0.314	0.679	0.708	0.785	0.314	1.692	0.247	0.307
		vdv	1.192	1.699	2.748	2.142	1.284	3.726	0.681	0.775
		rqm	0.797	1.136	1.838	1.432	0.859	2.492	0.455	0.518
15	20	rms	0.240	1.824	0.198	0.277	0.199	1.653	0.186	0.284
		vdv	0.508	4.067	0.474	0.646	0.525	3.677	0.398	0.625
		rqm	0.340	2.720	0.317	0.432	0.351	2.459	0.266	0.418
	30	rms	0.291	1.830	0.228	0.313	0.185	1.714	0.197	0.301
		vdv	0.970	4.075	0.573	0.792	0.467	3.809	0.483	0.715
		rqm	0.648	2.725	0.383	0.530	0.313	2.547	0.323	0.478
	40	rms	0.191	1.887	0.280	0.366	0.188	-	-	0.315
		vdv	0.385	4.194	0.911	1.136	0.512	3.921	6.611	0.794
		rqm	0.257	2.805	0.609	0.760	0.343	-	-	0.531

	no discomfort		uncomfortable
	little discomfort		very uncomfortable
	quite uncomfortable		extremely uncomfortable

The results obtained from the assessment of vibrational comfort in graphic form, according to the VDV and SEAT index, are presented in Figures 12 to 15.

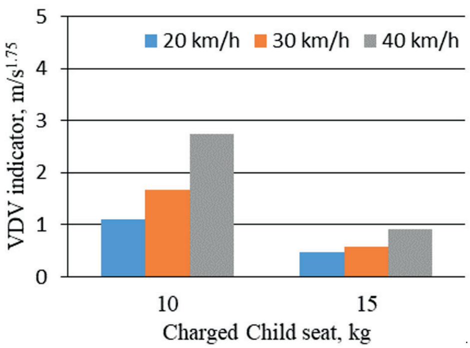

Fig. 12. VDV values of the accelerations registered on the seat of the "A" car child seat

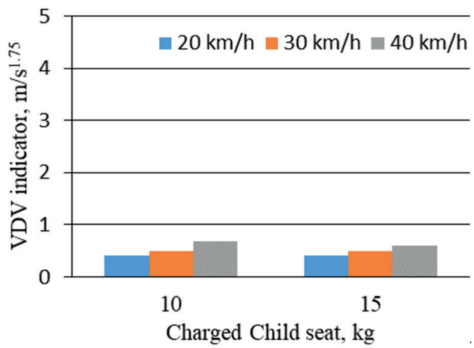

Fig. 13. VDV values of the accelerations registered on the seat of the "B" car child seat

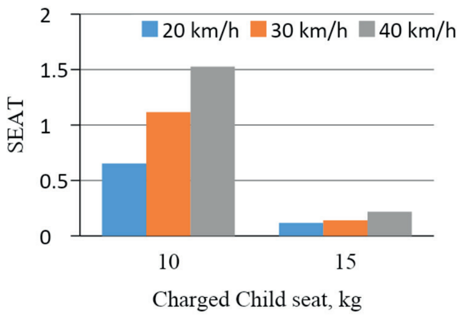

Fig. 14. SEAT indicator for "A" car child seat

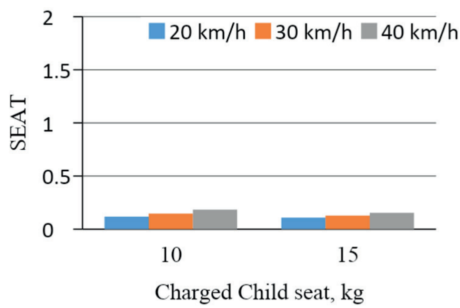

Fig. 15. SEAT indicator for "B" car child seat

6. Conclusions

The tests were aimed at checking and assessing the vibrational comfort of children (transported in car child seats) during traversing a standard speed bump by a passenger car.

Completed research has shown that the highest acceleration values occur on the basis of the ISOfix used to attach car child seats and they differ significantly in terms of quantity and quality from the acceleration courses recorded in other areas. Based on accelerations r.m.s., it can be concluded that the vibrations of the seats of the tested child seats, loaded with a mass of 15 kg, do not cause discomfort when car traverses the speed bump with a speed of 10 km/h and 20 km/h. A slight crossing of the border of discomfort during the driving car, made was recorded only on the seat of the "A" car child seat, which during the tests was loaded with a mass of 10 kg.

In most tests, increasing the speed of the car traversing the speed bump caused increasing the effective values of r.m.s. accelerations recorded both on the seats and backrests of the car child seats tested.

It is worth noting that the car seats have been stabilized using the ISOfix base. It separates the child seat from the rear car seat and the child seat is more stable than when mounted with standard seat belts. This method of attachment may, however, cause deterioration of the vibrational comfort of children transported in car child seats. The adverse effects of separating the car child seats from the rear seat using the ISOfix base are confirmed by effective accelerations r.m.s. registered on the seats of car child seats charged with a mass of 10 kg, which were higher than the effective accelerations r.m.s. recorded on the rear car seat. The main conclusion is to consider the possibility of extending the ISOfix base (fixing car child seats) with vibration damping elements that are transferred from the car body to child seats.

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