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CARGO SECURING – COMPARISON OF THE SELECTED TRUCKS

Summary. The paper deals with a comparison of shocks (values of acceleration coefficients and inertial forces) of two types of vehicles (T-810 and T-815 MK IV) during transport experiments on a motorway. The measurement was performed using an OM-CP-ULTRASHOCK-5 three-axial accelerometer with a datalogger and calibration certificate. The goal of the paper is to accept or reject a hypothesis of the existence of a statistically significant difference between the values of the acceleration coefficients generated by the two vehicles. The statistical analysis of the measured data was done with use of two parameters. The results of the analysis show statistically significant differences between the examined vehicles. Based on the performed statistical analysis, the effect on cargo securing is demonstrated.

1. INTRODUCTION

Every year, hundreds of millions of tons of cargo are transported in the Czech Republic (CR). In 2017, it amounted to 570,976,000 tons, which is an increase of almost 28% compared with 2013, when it was only 447,367,000 tons. In 2017, road transport accounted for more than 80% of the total volume, which was 459,433,000 tons of cargo [1]. In addition, the volume of road cargo transport in the CR has been growing steadily since 2013.

Similar numbers can be seen in other countries of the European Union (EU), such as Austria or Slovakia [1]. A steady gentle increase in road transport also occurs within the EU (28 countries). Although in 2013 the volume of road transport equaled 13,772,040,000 tons of cargo, in 2017, it rose to 14,608,049,000 tons, an increase of more than 6% [2].

By comparison, it is clear that the growth rate of road cargo transport in the CR is considerably higher than the European average. These increasing volumes are making ever higher demands for transport infrastructure. Above all, the main network of motorways is overloaded and rapidly wearing out [3].

According to statistics, a large number of trucks are overloaded during transport. The largest number is mainly in the segment of trucks up to 3.5 tons, whereas in 2016, it totaled 697 overloaded vehicles from the 1,370 weighed, which is almost 51%. Of the total number of 6,586 trucks weighed by the Czech police in 2016, 2,754 of them were overloaded, or nearly 42% [4]. Violation of these maximum permissible weights of trucks (including trailer) also contributes to faster wear of main roads and shortens their expected lifetime. There are other offenses that contribute to this rapid damage to roads [5]. The most important of these is the non-observance of specified speed limits, including bypassing or disconnecting the speed limiters that are usually equipped in trucks.

Generally, at higher speeds, trucks (or any vehicles) generate more shocks that affect the roads, vehicles, drivers, and loads [6]. These acceleration shocks can be expressed as a multiple of normal gravity acceleration (g = 9.81 $m \cdot s^{-2}$) by means of dimensionless acceleration coefficients in individual axes (c_x, c_y and c_z).

Another option is to calculate the inertial forces acting on the cargo fastening systems by using acceleration coefficients found in the individual axes. The calculation of these inertial forces acting on the fastening systems is very helpful in determining both the type and carrying capacity of the fastener. Such an approach is also used in a key European standard that addresses the issue of cargo securing EN 12195-1:2010 [7].

The effect of greater than expected shocks may then result in a reduction in the lifetime of any given road, as well as the vehicles and fasteners used to secure the cargo. However, these shocks may have more fatal consequences if the magnitude of the inertial forces acting on the cargo is greater than the load capacity of the fasteners, causing the cargo to be released and, in extreme cases, leading to traffic accidents.

According to the European Commission's Transportation Department, it is estimated that up to 25% of accidents involving trucks can be attributed to improper or insufficient cargo securing [8]. Traffic accidents can result in death or injury to persons, damage or destruction of cargo, transport vehicles or other technical means, transport infrastructure, and environmental damage (e.g. leakage of operating fluids) [9].

The aim of the paper is to experimentally demonstrate the difference between selected vehicles in terms of the effects of shocks on cargo (cargo securing) in the context of the EN 12195-1:2010 requirements. The knowledge of the magnitude of shocks, respectively of cargo securing requirements, enables to optimize the whole fastening system and thus increase road safety.

2. CARGO SECURING – LITERATURE REVIEW

Concept of Cargo Securing is based in the EU and in the CR mainly from the European standard EN 12195-1:2010 Load Restraining on Road Vehicles – Safety – Part 1: Calculation of Securing Forces [7]. The European Standard is based on empirical studies and presents statistically evaluated values of acceleration coefficients:

c_x – the acceleration coefficient in the longitudinal direction (x-axis) for forward/backward movements is 0.8/0.5;

c_y – the acceleration coefficient in the transverse direction (y-axis), displacement/tilting is 0.5/0.6; and

c_z – the vertical acceleration coefficient (z-axis) is 1.0 [7].

In addition to these acceleration coefficients, the European Standard contains the values of the coefficients required for the safety coefficient or friction coefficient calculations. The crucial part of the standard provides formulas and approaches for calculating the securing forces that correspond to assumed inertial forces. In other words, it is a calculation of the required strength of such items as fastening straps with respect to the assumed magnitude of the inertial forces acting during transport [7].

The issue of using fastening straps is determined by European standard EN 12195-2:2003 Load Restraint Assemblies on Road Vehicles – Safety – Part 2: Web Lashing Made from Man-made Fibres [10]. European standards (mainly [7]) develop further guidelines, codes, agreements, and best practices that apply within the EU. These include European Best Practice Guidelines on Cargo Securing for Road Transport from 2014 [11] which, in addition to European Standards, follow the IMO/ILO/UNECE Code of Practice for Packing of Cargo Transport Units which deals with packing, fastening, safety, and protection health at work [12].

Specific methods of transport are determined by separate documents. For the transport of dangerous cargo, the European Agreement Concerning the International Carriage of Dangerous Goods by Road is used [13]. For excessive and oversized cargos, European Best Practice Guidelines for Abnormal Road Transport is commonly used [14]. It is also worth mentioning selected national approaches, where Germany is the leader in the EU and a major contributor to the EU transport performance (22% of total transport performance in the EU in 2017). The issue of cargo securing is well developed within the guidelines of the Association of German Engineers VDI 2700:2009 Securing of Loads on Road Vehicles [15].

Approaches to cargo securing are discussed by several authors in monographs. Factors influencing cargo securing and how to fix top-over lashing using fastening straps is discussed by T. Lerher in his book Cargo Securing in Road Transport Using Restraining Method with Top-Over Lashing [16]. A similar issue is dealt with by G. Grossmann and M. Kassmann in their monograph, Safe Packaging and Load Securing in Transport [17]. The authors emphasize the function of packing and methods of cargo fastening, including related mathematical models. A complex solution, not only of the general principles of fastening, but also of the specificity of the oversized cargo and its transport by various types of transport, is the subject of W. Galora and his colleagues in Carriage and Securing of Oversize Cargo in Transport [18].

In following articles in scientific journals and conference proceedings, the issue of cargo securing is developed relatively sporadically. The area of fastening, using fastening straps in accordance with the calculations of European standards, is discussed in articles by J. Jagelcak and J. Gnap [19] as well as J. Jagelcak and J. Saniga [20]. Measuring and analyzing vehicle acceleration through the experiment is further addressed by A. Linins and D. Berjoza [21], who, in addition to technical aspects, also discuss cargo areas.

3. TRANSPORT EXPERIMENT

For the purposes of statistical evaluation and acceptance or rejection of particular hypotheses, a transport experiment was carried out to measure the data covering shocks generated by analyzed vehicles. Shocks, more precisely the values of the acceleration coefficients, were measured using an accelerometer with a datalogger and a calibration certificate OM-CP-ULTRASHOCK-5 with a measuring range of $\pm 5g$. The measurements were made on the following trucks:

- Tatra 810-V-1R0R26 13 177 6×6.1R medium freight off-road vehicle (hereinafter T-810) [22] and
- Tatra 815-260R81 36 255 8×8.2 Multilift MK IV container carrier (hereinafter T-815 MK IV) [23].

The measuring device was placed in the middle of the cargo space (on the floor) at the both trucks. The route of the transport experiment (Fig. 1) was a section of the D1 motorway between Vyškov and Brno (Czech Republic), which is 27-km long. Road profile conforms to highway according the standard ČSN 736101:2018 [24].

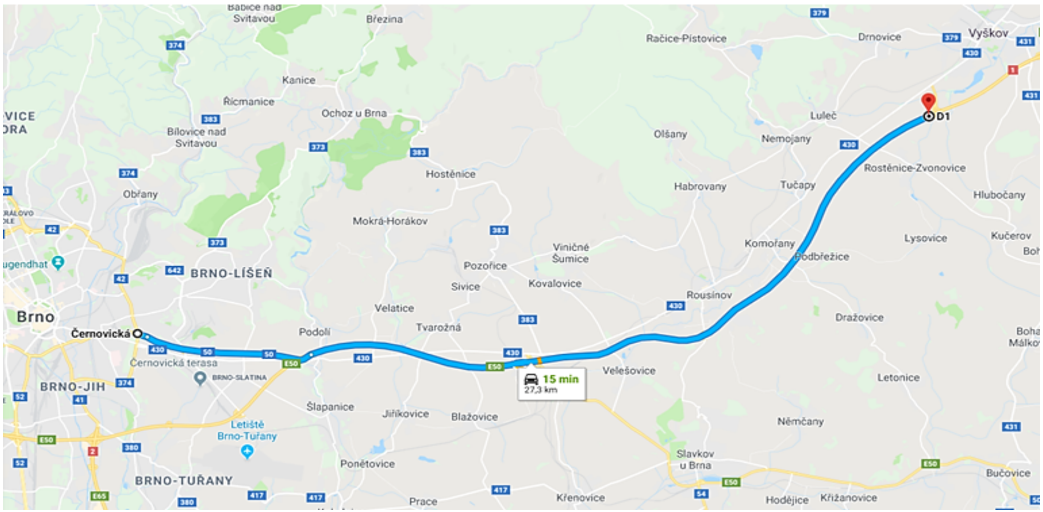

Fig. 1. Transport Route. Source: [25]

The transport experiment was carried out under optimal climatic and transport conditions without cargo in June 2018. The temperature range during the transport experiment was 21–25°C. No rainfall was recorded at the time of the measurements, the road was dry, and there was excellent visibility. The ride was not further restricted by traffic jams or other poor traffic conditions in the section. The traffic situation allowed the driver to smoothly pass through the Vyškov – Brno section. The vehicles used for the transport experiment were in standard configurations, such as those used by the Army of the Czech Republic.

During the transport experiment, two data sets were obtained, including the acceleration coefficients in each axis for both transports. The transport experiment on the T-810 was denoted as data set 1 (d_1), and on the T-815 MK IV data set 2 (d_2). The T-815 MK IV used the empty ISO 1C container. The ranges of d_1 and d_2 are as follows:

- d_1: 4,059 values, i.e. 1,353 values for each axis (see Fig. 2).
- d_2: 4,059 values, i.e. 1,353 values for each axis (see Fig. 3).

The measured data are further used in the fastening models and in the calculation of the inertial forces acting on the fastening strap used. The inertial forces in the x and y axes (F_{xi} and F_{yi}) are then calculated using the relations (1) and (2) from [7]:

$$F_{xi} = \frac{(c_x - \mu \cdot c_z) \cdot m \cdot g}{2n \cdot \mu \cdot \sin \alpha} \cdot f_s \qquad [\mathrm{N}] \tag{1}$$

$$F_{yi} = \frac{(c_y - \mu \cdot c_z) \cdot m \cdot g}{2n \cdot \mu \cdot \sin \alpha} \cdot f_s \qquad [\mathrm{N}] \tag{2}$$

where c_x, c_y and c_z are acceleration coefficients in particular axes; μ is a friction factor; m is the total mass of the load; g is the gravity acceleration; f_s is the coefficient of safety for frictional lashing; n is the number of lashing straps; and α is the vertical lashing angle.

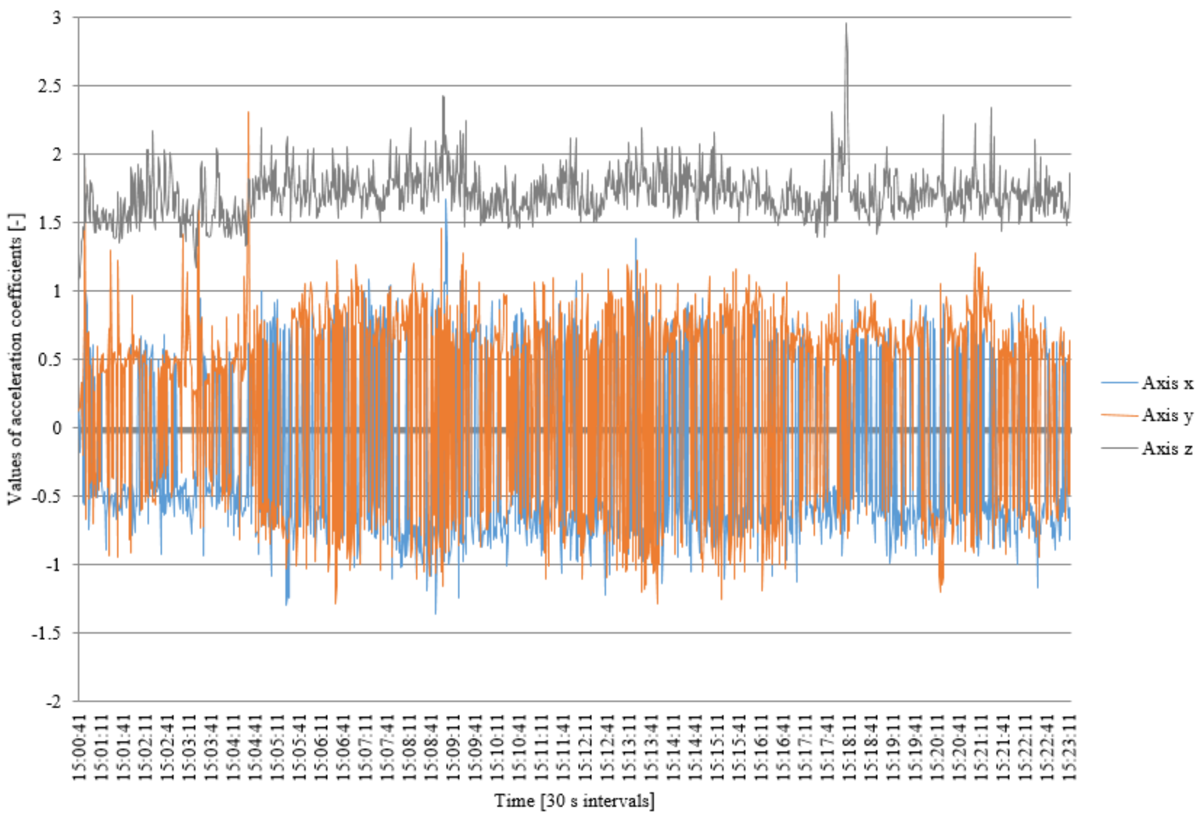

Fig. 2. Graphical representation of d_1 (T-810). Source: Own

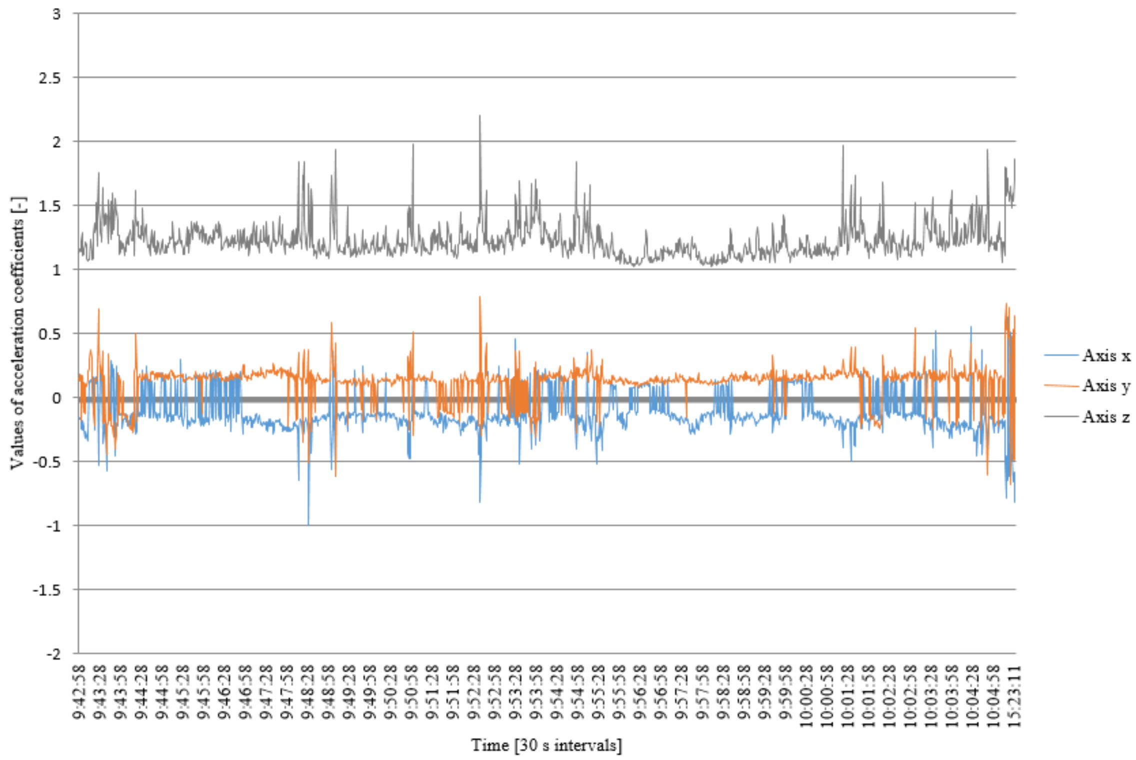

Fig. 3. Graphical representation of d_2 (T-815 MK IV). Source: Own

The cargo attachment model is based on the attachment of two 1,200 × 800 × 1,600 mm EUR wooden pallets. Each pallet unit has a weight of 1,000 kg, i.e., the total weight of the model cargo is m = 2,000 kg. The model defines the required pulling force for one piece of the fastening strap (Lashing Capacity, LC), i.e., the number of fastening straps used in the calculation is n = 1. The values used for the coefficient of friction wood-plywood is μ = 0.3 (according [12]), which represents basal variant (worst value of coefficient of friction) for these surface type, and the safety coefficient is $f_s(x)$ = 1.1 for x axis and $f_s(y)$ = 1.25 for y axis [7]. The angles used for both data sets (α_0, α_1, α_2) are based on the method of fastening the pallet units (see Fig. 4 and Fig. 5).

The cargo fastening model used actual requirements on the handling units and capabilities of the cargo space of the vehicle. The dimensions of the loading area of the T-810 were 4,660 × 2,470 mm, offering a loading area of approximately 11.5 m^2 [26]. For fastening, floor fastening rings with a load-bearing capacity of 2,000 daN were available for each T-810 vehicle as standard and a single tie-down strap whose parameters are not relevant to the design of the model (any strap available on the market can be used). The dimensions of the loading area of the ISO 1C container placed on the T-815 MK IV were 5,870 × 2,330 mm, offering a loading area of approximately 13.7 m^2 [27]. The non-removable ANCRA equipment, which is an integral part of the ISO 1C storage containers, was also used for fastening. Three ANCRA multipurpose side strips were included for attaching fastening straps with a carrying capacity of 1,500 daN per fastening ring, 22 ANCRA fastening straps with LC = 1,500 daN, and length 3,500 mm [28,29].

The difference in loaded cargo was mainly due to the width of the loading area, which allows the T-810 to store two pallet units transversely to the direction of travel of the vehicle (see Fig. 4). The angle α_1 in this case is 88.75° due to the very small distance of the fastening eye (see left red point in Fig. 4) from the heel of the pallet unit (35 mm). The length of the strap is at least 5,601 mm. The T-810 uses commonly available fastening straps, which means that loaders chose an extended length strap.

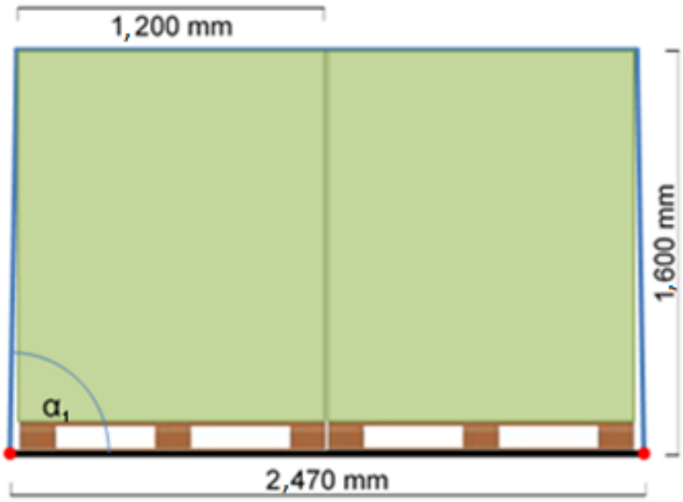

Fig. 4. Fastening of load on T-810. Source: Own

In the case of the ISO 1C container, one pallet unit was positioned transversely and the other one longitudinally to the vehicle direction of travel (see Fig. 5). The ISO 1C container illustrates the possibility of fastening using the lower multi-angle side straps ANCRA (angle α_0), which would require a longer strap (at least 4,661 mm) than the ANCRA strap. The advantage of this fastening method is the higher magnitude of angle (α_0 = 82.87°). The required angle is smaller and, with respect to the same system, the model mount is the same as α_2. Using the goniometric functions, its magnitude was determined as α_2 = 76.17°. The required length of the strap was 3,380 mm, which made it possible to use the ANCRA strap that is a standard part of the ISO 1C storage container.

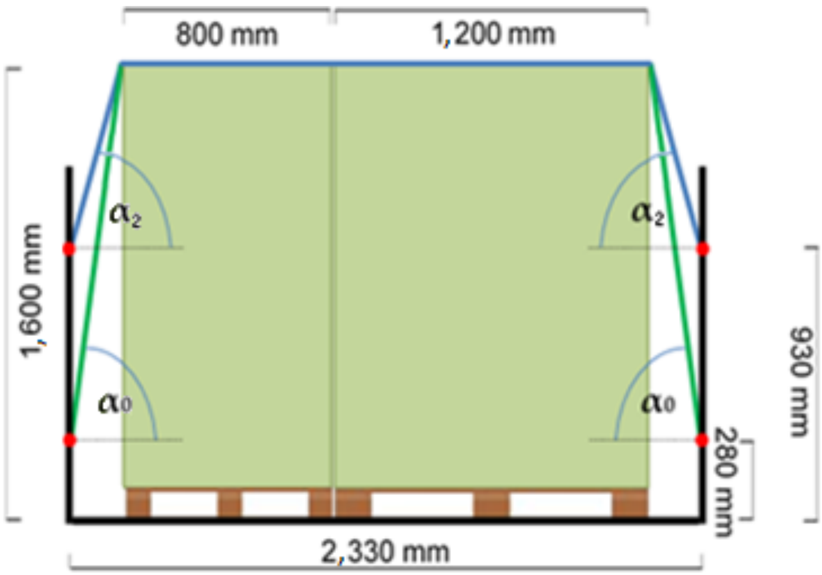

Fig. 5. Fastening of load on T-815 MK IV. Source: Own

4. STATISTICAL ANALYSIS OF ACCELERATION COEFFICIENTS

Descriptive statistics was used for a comparison of d_1 and d_2, such as mean values − arithmetic means of absolute values of acceleration coefficients, variances, and medians of the absolute values of acceleration coefficients – see results in Tab. 1.

Table 1

Arithmetic mean, median, and variance of absolute values of acceleration coefficients for d_1 and d_2 in all three axes

	Acceleration coefficients [–]								
	Arithmetic mean			**Median**			**Variance**		
	c_x	c_y	c_z	c_x	c_y	c_z	c_x	c_y	c_z
d_1	0.6012	0.6396	1.6381	0.5900	0.6100	1.6200	0.2923	0.4059	0.0304
d_2	0.1854	0.1711	1.2275	0.1700	0.1500	1.2000	0.0266	0.0201	0.0188

** The accelerometer has a displaced axis of about 1g (due to gravity acceleration), i.e., the values in the z axis are higher by the value of gravitational acceleration (1g) in case of arithmetic mean and median.*

Tab. 1 shows the big difference between d_1 and d_2. For d_1, i.e. in the case of the T-810, the normative limit given in EN 12195-1:2010 is exceeded in the y axis for arithmetic mean and median of the absolute values of acceleration coefficients ($c_y = 0.6$).

Before the statistical analysis was performed, normality tests were performed using skewness and kurtosis coefficients [30], and normality was also verified graphically using histograms and Q-Q plots. In these tests, minor deviations from normal distribution were identified but the graphical analysis did not show any substantial deviations from normality because theoretical quantiles and corresponding empirical quantiles lay approximately in a line. For this reason, asymptotic statistical test, based on the assumptions of asymptotic normality were used. When testing the relevant hypothesis, the STAT1 software product was used [30].

For the purpose of testing, null and corresponding alternative hypothesis with the designations H and A respectively, were formulated:

- H: The mean values and variations in the acceleration coefficients measured at T-810 on the motorway (d_1) are not statistically significantly different from those measured on the T-815 MK IV on the motorway (d_2).
- A: The mean values and variations in the acceleration coefficients measured at T-810 on the motorway (d_1) are on average higher than those measured on T-815 MK IV on the motorway (d_2).

To verify the hypothesis H, partial hypotheses (six tests) were separately tested for individual axes and each of the tested characteristics. A right-hand test was used to test the hypothesis A. Tab. 2 shows the appropriate alternative hypothesis for d_1 and d_2.

Table 2

Mathematical writing of alternative hypothesis

	Acceleration coefficients [–]					
	Arithmetic mean			**Variance**		
	c_x	c_y	c_z	c_x	c_y	c_z
d_1 and d_2	$\mu_1 > \mu_2$			$\sigma_1^2 > \sigma_2^2$		

The testing was performed using the critical region, calculating the value of the test statistic and comparing it with the relevant critical region. If the value of the test statistic falls into the critical region, the null hypothesis H is rejected at the significance level α. For all tests, significance level $\alpha = 0.05$ was used.

Based on the results of the statistical analysis, the null hypothesis H was rejected at the significance level $\alpha = 0.05$. With 95% probability, we can assert that mean values and variations of acceleration coefficient values of d_1 are, on average, higher than for d_2.

The differences between the vehicles were significant and it can be assumed that the null hypothesis *H* would be rejected at a lower significance level than $\alpha = 0.05$ and the statistically significant difference between d_1 and d_2 would be demonstrated. Consequently, assuming a *ceteris paribus*, the T-810 will, on average, generate higher shocks (acceleration coefficient values) than the T-815 MK IV with the empty ISO 1C container in a standard configuration. This fact can have a significant effect on the transported goods on the vehicle body and, in the container, respectively. For the transport of sensitive goods, it would far more advantageous to use the container in the T-815 MK IV.

5. MODEL VALUES OF INERTIAL FORCES

Using the relations (1) and (2), the average values of the inertial forces in the *x* and *y* axes for d_1 and d_2 (F_{xi} and F_{yi}) [7] are calculated, without considering the direction of those inertial forces (sign). Average values of the inertial forces are compared with the values of inertial forces in the *x* and *y* axis using normalized acceleration coefficients for a given vehicle type (F_{xn} and F_{yn}). The results of the observed forces are summarized in Tab. 3. The difference in the forces F_{xn} and F_{yn} is given only by the method of mounting the pallet units and the differences in the angles α_i that attach the strap to the plane of the vehicle floor (container).

Table 3

Sizes of inertial forces detected

	Arithmetic mean of inertial forces [N]			
	F_{xi}	F_{yi}	F_{xn}	F_{yn}
d_1	30,363	19,820	17,989	12,265
d_2	18,178	10,481	18,522	12,629

Tab. 3 shows that there is a major difference between the analyzed vehicles. The value of the mean inertial force in the *x* axis for d_1 is 1.67 times higher than for d_2. A similar situation exists in the *y* axis, where is F_{yi} 1.89 times higher for d_1 than for d_2. When comparing the inertial forces F_{xi} and F_{yi} with inertial forces using normalized acceleration coefficients, it is clear that while T-810 is insufficient in EN 12195-1:2010, the T-815 MK IV does not exceed the normative limits.

It is therefore concluded that the T-810 in the standard configuration generates, under the *ceteris paribus*, higher shocks (values of inertial forces) than the T-815 MK IV in a standard configuration with the empty ISO 1C container.

6. CONCLUSION

The results of the statistical analysis can be considered as a case study that found partial deficiencies in the concept of cargo fastening using the procedures defined in EN 12195-1:2010. At the significance level $\alpha = 0.05$, for c_x, c_y and c_z it is valid that the arithmetic means of absolute values are higher for d_1 than for d_2. The variances of values are higher for d_1 than for d_2 between the standard T-810 and the T-815 MK IV with the empty ISO 1C container, which are used within the framework of the Czech Republic Army and the components of the Integrated Rescue System of the Czech Republic. In addition, the T-810 has exceeded normative limits (defined acceleration coefficients or calculated inertial forces). Deviations from the conclusions of EN 12195-1:2010 are also foreseen for other vehicles and especially for lower quality road, where is the link to a critical transport infrastructure [31, 32].

At present, cargo forwarding and forwarding companies are in the forefront of tracking transport parameters, one of them being acceleration shocks. Their evaluation can optimize the attachment of loads and ensure greater safety in cargo transport, including passengers, etc. The importance of such optimization will have a positive impact on the economy of shipment as well as forwarding companies. Even greater contributions can be made to the security forces such as the military and integrated rescue systems or during transports of dangerous cargo [33].

The prerequisite for further research will be the gradual expansion of these case studies with the aim of generalizing them and launching a discussion over the parameters set out in EN 12195-1:2010, along with related standards and documents. The goal should be a new concept for determining vectors of acceleration coefficients in individual axes that will reflect changes in the transport system over the last three decades, those yet to come and the specifics of the transport market. More sophisticated methods such as spectral analysis [34, 35] or application of extreme value theory [36] will be used in further research.

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