Comparison of Cargo Securing Methods During Transport on Different Quality Roads

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Abstract. The chapter compares the values of shocks (acceleration coefficients and securing forces) generated by the Tatra T-810 on high-quality road (highway) and lower-quality road (road paved with granite blocks). To obtain primary data, a transport experiment was performed to measure shocks (acceleration coefficients) during transportation on given types of roads using a three-axis accelerometer with a datalogger and a calibration certificate – OM-CP-ULTRASHOCK-5-CERT. For each (transport) route two datasets were obtained, which were analysed using suitable statistical tools – characteristics. The mean values and variations of measured acceleration coefficients on the roads are compared. The graphical comparison of the roads studied is covered in a separate section. Furthermore, the required securing forces in the x and y axes are calculated according to EN 12195-1:2010 and are compared not only for individual datasets, but also with the theoretical securing force based on normative values of acceleration coefficients. It also includes the determination of the probability of exceeding, respectively double exceeding of the "normatively determined" limits of securing forces. The results of the transport experiment show that the magnitude of generated shocks is even higher at a lower average transport speeds on a low-quality roads. The distribution of acceleration coefficient values also differs for both roads.

Keywords: Transport experiment · Road safety · Cargo securing · Acceleration coefficients · Securing forces · Statistical analysis

1 Introduction

Within the European Union (EU), over 76% of cargo is transported using road transport [6]. Over the last ten years (2008–2017), a total of 147,047,868,000 tons of freight was transported across the EU, an annual average of 14,704,787,000 tons of transported cargo [5].

Due to these large volumes of cargo transported by road, a high number of roads are overloaded. According to the Road Transport Services Center, established by the Ministry of Transport of the Czech Republic, over a half of all vehicles are overloaded during weight checks, which amount to over 2,000 per year in the Czech Republic [2].

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According to the Regional Road Administration and Road Maintenance statistics, a single truck will damage a road more than 10,000 passenger cars [1]. Cargo transport makes high demands on road infrastructure that is more quickly worn out (damaged). Annual maintenance is not always able to ensure its required quality.

Quality of roadways directly affects the magnitude of the inertial forces that affect cargo during transport. Generally, on a damaged road, characterized by a large amount of unevennesses (holes, seals, etc.), higher values of acceleration coefficients (shocks) that directly affect the magnitude of inertial forces are assumed. On the basis of the assumed size of inertial forces acting on transport, it is necessary to choose appropriate methods of securing (fastening) cargo and evaluating the lashing capacity of the respective fastening means.

Determining the magnitude of the inertia in the actual transport is possible by using a suitable measuring device (accelerometer) and the appropriate calculation, mainly by using the formulas from the norms, e.g. EN 12195-1:2010 [4]. Selected cargo shippers and carriers use accelerometers to detect undesirable shocks (acceleration) during shipment of particularly fragile or otherwise sensitive goods (dangerous goods etc.). These are, for example, multinational companies DHL [3], GEIS [7] or TNT [15].

Exceptions do not even apply in an advanced army, such as the United States Army, which complements its transport and transport means (mainly containers) with a set of measuring devices that monitor (among others) the cargo space [14]. The temperature, relative humidity, acceleration in individual axes, etc. are determined in the respective transport means.

From the point of view of inertial forces influencing cargo, the key values of acceleration coefficients in individual axes are primarily influenced by the following three basic factors:

– vehicle,
– driver,
– road [11, 18].

In the case of a vehicle, it is also important whether it is moving with or without cargo. The key technical factors of the vehicle are its tires, chassis, structure of the vehicle hull and its connection with the chassis, including the age of the vehicle and its individual components, etc. The driver's driving style is a significant factor, especially the speed of the vehicle as well as driver's skills, experience and mental condition [17, 24].

The purpose of this chapter is to prevent problems associated with incorrect or insufficient cargo securing through knowledge of the transport parameters – the roads before it starts – and thus increase transport safety. The risks associated with inertia forces on cargo are generally higher for specific shipments that are carried by the military or components of the Integrated Rescue System [19].

2 Transport Experiment

The transport experiment was carried out on two types of roads using a Tatra T-810 6x6 (T-810) with mileage less than 45,000 km. The first type of highway was the D1 highway, measured from Brno to Vyškov and back. The second type was a lower quality transport road (third class road); a paved road measured from the Vyškov to Dědice and back [25].

The transport experiment was undertaken by one professional driver and a 3-axis accelerometer with a datalogger and a calibration certificate – OMEGA-OM-CP-ULTRASHOCK-5 (see the Fig. 1).

A measuring range of ±5 g was used to obtain the values of the acceleration coefficients. A sampling rate of 512 Hz was used with a record for every second of the highest (or possibly) lowest value of the respective acceleration coefficient in the given axis (x, y and z) [8]. The axes are designated according the Fig. 2: x – longitudinal, y – transverse and z – vertical.

Fig. 1. Mounting of the measuring device [25].

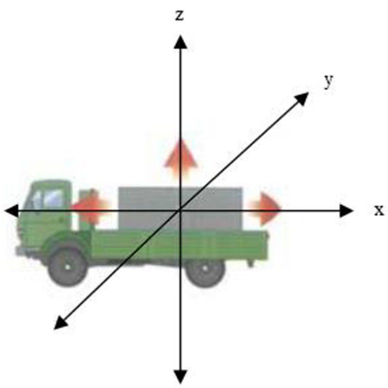


Fig. 2. Axes designation [13].

The accelerometer was mounted on the steel center frame of the vehicle body in the front of the T-810 load compartment and the transport experiment was carried out without any load and in optimal climatic conditions included dry roads, excellent visibility, absence of congestion and rainfall. Outdoor temperature was in the range of 7–11 °C.

2.1 Methods

To accomplish a comparison of the above described roads, as specified in Sect. 2.2, descriptive statistics were used and basic descriptive characteristics were found (mean values – arithmetic mean, modus and median, variance, coefficients of skewness and kurtosis). Comparison also includes the detection of extreme values in individual axes (both positive and negative). The selected values are compared with the use of one and two-choice tests of statistical hypotheses on the equivalence of mean values (arithmetic mean of absolute values of acceleration coefficients) and variance (part 2.3). The significance level $\alpha = 0.05$ is used for all tests.

In a separate Sect. 2.4 a graphical comparison of the distribution of measured values of acceleration coefficients on the examined roads is shown.

In a separate section, the securing forces needed to properly secure the load are calculated, statistically compared for individual datasets, as well as compared with theoretical securing forces based on normative values of acceleration coefficients. Statistical equality tests are used for comparison. The section also includes the determination of the probability of exceeding; respectively double exceeding of theoretical securing forces according to EN 12195-1:2010.

The basic parameters for carrying out statistical equality tests are used in the same way as were used for the comparison of experimentally determined data (acceleration coefficients).

The probability of exceeding, respectively double exceeding of the "normatively determined" values of the securing forces in the x and y axes. The z-axis (F_z) is not calculated in accordance with EN 12195-1:2010 because it is assumed that F_z is always less than (or equal to) at least one of the other forces (F_x or F_y).

Lower Bound (LB), Upper Bound (UB) and Parameter Estimate (PE) are calculated for each parameter. The existence and non-existence of a statistically significant difference at the required level of significance can be deduced from the above mentioned boundaries and PE.

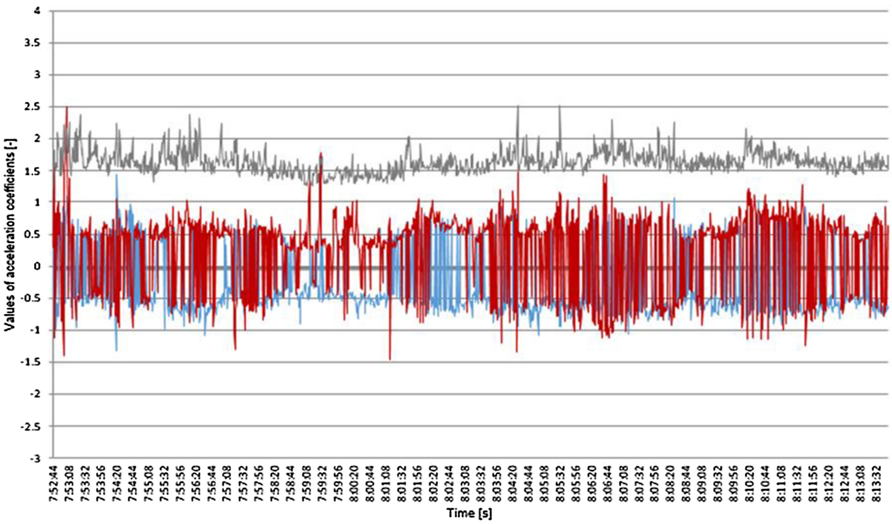
2.2 Basic Descriptive Characteristics of Measured Data Files

The first data file (dataset 1) was obtained on the Brno-Vyškov (highway) route (see the Fig. 3). In a stretch of 27.0 km long, a total of 3,804 values of acceleration coefficients were recorded and the average vehicle speed was 76.66 km·h^{-1} [25].

The basic descriptive characteristics of dataset 1 as well as the extremes in the individual axes, in both positive and negative directions are illustrated in Tables 1 and 2.

According to Table 1, a higher value of kurtosis coefficient in z-axis can be identified which is slightly elevated (positive), while in the other two axes, the values are less than 0. This is due, among other things, to the displacement of the coordinate axis due to gravity acceleration.

Z-axis variance is also more than 13 times smaller than the y-axis, respectively almost 10× in the x-axis. Extremes – the highest and lowest values of the acceleration coefficients in the individual axes are given in Table 2. The highest value of the acceleration coefficient was in the y-axis where the measured value $c_y = 2.51$, corresponding to 2.5 times the gravity acceleration g [25].



Legend: blue – x axis, red – y axis, grey – z axis.

Fig. 3. Dataset 1 – raw data [25]. (Color figure online)

Table 1. Dataset 1 – basic descriptive characteristics.

Characteristics	x	y	z
Arithmetic mean	−0.2953	0.2284	1.6381
Modus	−0.6100	0.5100	1.6000
Median	−0.5400	0.5000	1.6200
Variance	0.2923	0.4059	0.0304
Skewness coef.	1.0464	−0.5862	1.0127
Kurtosis coef.	−0.5327	−0.7773	2.2971

Source: [25].

Table 2. Dataset 1 – extremes of measured acceleration coefficient values.

Extremes	x	y	z
Positive	1.4400	2.5100	1.5300
Negative	−1.3200	−1.4700	–

Source: [25].

The second data file (formally identified with Dataset 2) was obtained on the route Vyškov–Brno (highway). In a 27.0 km long section, a total of 4,059 values of acceleration coefficients were recorded and the average speed of the vehicle was

71.84 km·h^{-1}. The basic descriptive characteristics of Dataset 2 and the extremes in the individual axes, in the positive and negative directions, are presented in Tables 3 and 4.

Table 3. Dataset 2 – basic descriptive characteristics.

Characteristics	x	y	z
Arithmetic mean	−0.2530	0.2226	1.7075
Modus	−0.6500	0.6900	1.6700
Median	−0.5900	0.5700	1.6900
Variance	0.4330	0.5169	0.0291
Skewness coef.	0.7439	−0.5277	1.1093
Kurtosis coef.	−1.1524	−1.2530	5.5130

Source: [25].

Table 4. Dataset 2 – extremes of measured acceleration coefficient values.

Extremes	x	y	z
Positive	1.6700	2.3100	1.9600
Negative	−1.3600	−1.2900	–

Source: [25].

Table 3 shows a higher coefficient of kurtosis in the z-axis. The highest measured value within Dataset 2 (Table 4) was in the y-axis ($c_y = 2.31$), roughly equivalent to 2.3 times the gravity acceleration g.

A third data set (formally marked with Dataset 3) was obtained on the route Vyškov–Dědice (the road paved with granite blocks). Over a 4.3 km long section, a total of 1,182 acceleration coefficient values were recorded and the average vehicle speed was 39.29 km·h^{-1}. The basic descriptive characteristics of Dataset 3 and the extremes in the individual axes, in the positive and negative directions, are presented in Tables 5 and 6.

Table 5 identified higher kurtosis in the z-axis. The highest measured value within Dataset 2 (Table 6) was in the z axis ($c_z = 3.11$), roughly equivalent to more than 3.1 times the gravity acceleration g.

A fourth data set (formally marked with Dataset 4) was obtained on the route Dědice–Vyškov (road paved with granite blocks). Along a 4.3 km long section, a total of 1,203 acceleration coefficient values were recorded and the average speed of the vehicle was 38.60 km·h^{-1}. The basic descriptive characteristics of Dataset 4 and extremes in individual axes, positive and negative, are given in Tables 7 and 8.

Table 7 shows the difference in variance of the z-axis, which is significantly lower than that of the other two axes. The highest measured is in the y-axis ($c_z = 2.70$), which corresponds to 2.7 times the gravitational acceleration g.

Table 5. Dataset 3 – basic descriptive characteristics.

Characteristics	x	y	z
Arithmetic mean	−0.1904	0.0730	1.9924
Modus	0.4500	0.4100	1.6000
Median	−0.5150	0.4500	1.9500
Variance	0.7927	1.0016	0.1784
Skewness coef.	0.1441	−0.2296	0.9992
Kurtosis coef.	−1.1163	−1.0862	1.9430

Source: [25].

Table 6. Dataset 3 – extremes of measured acceleration coefficient values.

Extremes	x	y	z
Positive	1.8300	2.2800	3.1100
Negative	−3.0800	−2.4400	–

Source: [25].

Table 7. Dataset 4 – basic descriptive characteristics.

Characteristics	x	y	z
Arithmetic mean	−0.4425	0.0562	2.0047
Modus	−0.8000	0.8300	2.0000
Median	−0.7300	0.4500	1.9500
Variance	0.7532	1.1867	0.1742
Skewness coef.	0.9505	0.0755	0.8825
Kurtosis coef.	−0.1423	−1.1141	0.7597

Source: [25].

Table 8. Dataset 4 – extremes of measured acceleration coefficient values.

Extremes	x	y	z
Positive	1.9700	2.7000	2.6300
Negative	−2.3000	−2.4200	–

Source: [25].

2.3 Comparison of Acceleration Coefficients

For the purpose of comparing a high-quality road (highway) with a poor quality road (paved with granite blocks), partial zero and alternative hypotheses were formulated to compare the individual datasets (d_1–d_4) in pairs. Two single-choice tests of partial statistical hypotheses were used for testing:

- mean values compliance test,
- variances compliance test.

The zero hypothesis is assumed to be valid (resp. partial zero hypotheses for the respective dataset pairs) concerning the parity of the relevant dataset parameters, for the mean values $\mu = \mu_0$, resp. variances $\sigma^2 = \sigma_0^2$. For an alternative hypothesis in the double – side test applies $\mu \neq \mu_0$, resp. $\sigma^2 \neq \sigma_0^2$. Subsequently, one-sided tests are performed to determine whether $\mu > \mu_0$ or $\mu < \mu_0$, resp. $\sigma^2 > \sigma_0^2$ or $\sigma^2 < \sigma_0^2$.

For test purposes, a critical value range was constructed and a test criterion value calculated.

To test the hypothesis an appropriate statistic $T = T(x_1, x_2,\ldots, x_n)$ is used, the so-called test criterion that has, when the zero hypothesis is valid, known probability distribution (Student's or t-distribution).

The area of these values of statistics is divided into two disjoint fields:

- $W_{1-\alpha}$ is the domain of accepting a zero hypothesis – a set of values that testify in favor of a zero hypothesis,
- W_α is a critical domain (domain of zero hypothesis rejection) – that testify in favor of an alternative hypothesis.

For example, for the hypothesis test of the mean value μ of the normal distribution zero hypothesis: $\mu = \mu_0 \rightarrow$ alternative hypothesis: $\mu > \mu_0$ will be critical domain $W_\alpha = \{t, t \geq t_{1-\alpha}(\nu)\}$, where μ_0 is the expected value of the parameter μ, t is the value of the test criterion and $t_{1-\alpha}(\nu)$ is quantile of Student's distribution – so-called critical value [12]. Tests for variances are performed analogously. For all tests, the chosen level of significance was $\alpha = 0.05$.

On the basis of these tests, the individual partial zero hypotheses were verified, from which the relevant conclusions are subsequently formulated.

A normality test was performed prior to statistical analysis. Normality was verified graphically using Q-Q plots [10], including the determination of skewness and kurtosis coefficients. Minor deviations from normality were found, especially when testing the kurtosis of distribution. However, the graphical analysis did not show significant deviations from normality, theoretical quantile and the corresponding empirical quantiles were approximately on a straight line [21].

The Stat1 software tool was used to perform statistical hypothesis tests [12].

In individual partial tests (Table 9), the hypotheses on equivalence of the mean values are always tested (arithmetic means in absolute value) $\mu_{i(abs)}$ for given values of acceleration coefficients in individual axes (c_x, c_y and c_z). Analogously, variances in acceleration coefficients in individual axes are tested. The aim of the tests is to find out whether the individual data sets (d_1–d_4) significantly statistically differ at the $\alpha = 0.05$ level of significance.

Table 9 shows that, using a mean value (arithmetic averages in absolute values), there is a statistically significant difference between individual datasets with the exception of d_3–d_4, where it shows the similarities of both files found on the same road in the opposite direction. A statistically significant difference between d_3 and d_4 was shown only in the axes x and y.

Table 9. Comparison of mean values (in absolute values) of acceleration coefficients in all three axes.

Characteristics	$\mu_{i(abs)}$		
Coef. / Dataset	c_x	c_y	c_z
d_1–d_2	$\mu_1<\mu_2$	$\mu_1<\mu_2$	$\mu_1<\mu_2$
d_1–d_3	$\mu_1<\mu_3$	$\mu_1<\mu_3$	$\mu_1<\mu_3$
d_1–d_4	$\mu_1<\mu_4$	$\mu_1<\mu_4$	$\mu_1<\mu_4$
d_2–d_3	$\mu_2<\mu_3$	$\mu_2<\mu_3$	$\mu_2<\mu_3$
d_2–d_4	$\mu_2<\mu_4$	$\mu_2<\mu_4$	$\mu_2<\mu_4$
d_3–d_4	$\mu_3<\mu_4$	$\mu_3<\mu_4$	NO

Note: *NO indicates the non-demonstration of a statistically significant difference between the monitored data files at the level of significance α = 0.05. Statistically significant differences demonstrated for all three axes are marked green.*

Source: [25].

From partial hypothesis tests it follows that, from the point of view of the mean values (arithmetic averages in absolute values), there is a statistically significant difference at the level of significance $\alpha = 0.05$ between a high-quality road (highway) and a lower quality road (paved with granite blocks). The conclusion is valid in both directions. Because it is valid, it means that values are statistically significantly lower (in all three axes) for datasets 1 and 2 compared to datasets 3 and 4.

Table 10 shows that, by using variances, there is a statistically significant difference between individual datasets with the exception of d_1 and d_2, respectively d_3 and d_4. Where the similarity can be seen in both pairs of files found on the same traffic path in the opposite direction. Statistically significant difference d_1–d_2 is only shown in the axes x and y. Between the d_3–d_4 datasets a statistically significant difference was not demonstrated in either of the axes.

Partial hypothesis tests show that, from the point of view of the variances, there is a statistically significant difference in the level of significance $\alpha = 0.05$ between a high-quality transport road (highway) and a lower quality road (paved with granite blocks). The conclusion is valid in both directions, because the results show that variances are statistically significantly lower (in all three axes) for dataset 1 and 2 compared to dataset 3 and 4. For some axes, it can be assumed that a statistically significant difference between the pairs of the dataset with a higher test strength (at the level of significance $\alpha = 0.01$) would be demonstrated.

Table 10. Comparison of variances acceleration coefficients across all three axes.

Characteristics	σ_i^2		
Coef. / Dataset	c_x	c_y	c_z
d_1–d_2	$\sigma_1^2<\sigma_2^2$	$\sigma_1^2<\sigma_2^2$	NO
d_1–d_3	$\sigma_1^2<\sigma_3^2$	$\sigma_1^2<\sigma_3^2$	$\sigma_1^2<\sigma_3^2$
d_1–d_4	$\sigma_1^2<\sigma_4^2$	$\sigma_1^2<\sigma_4^2$	$\sigma_1^2<\sigma_4^2$
d_2–d_3	$\sigma_2^2<\sigma_3^2$	$\sigma_2^2<\sigma_3^2$	$\sigma_2^2<\sigma_3^2$
d_2–d_4	$\sigma_2^2<\sigma_4^2$	$\sigma_2^2<\sigma_4^2$	$\sigma_2^2<\sigma_4^2$
d_3–d_4	NO	NO	NO

Note: *NO indicates the non-demonstration of a statistically significant difference between the monitored data files at the level of significance α = 0.05. Statistically significant differences demonstrated for all three axes are marked green.*

Source: [25].

2.4 Graphical Comparison of Roads

The individual datasets (d_1–d_4) can be viewed in terms of the number of values of the acceleration coefficients in the individual axes that fall within the respective intervals. Figures 4, 5, 6 and 7 show the frequencies of acceleration coefficients in individual axes, divided into intervals of multiples of gravitational acceleration (0.5 g).

It can be seen from Figs. 4, 5, 6, and 7 that the character of the distribution of values at individual intervals differs significantly between the tested roads. Although the

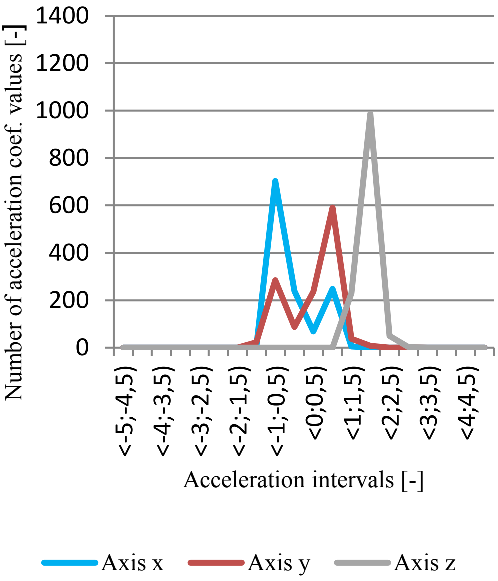


Fig. 4. Dataset 1 – frequency of acceleration coefficients [25].

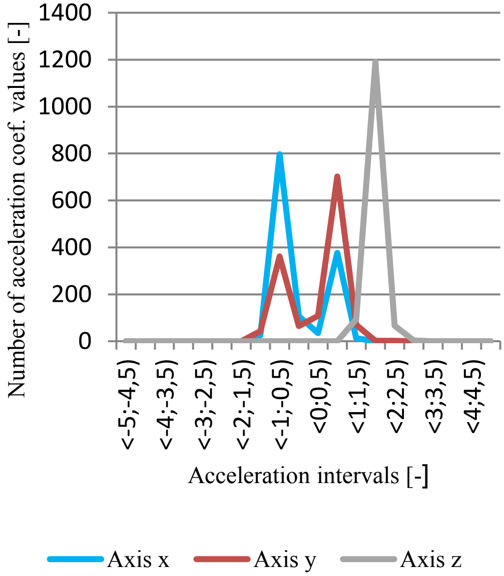


Fig. 5. Dataset 2 – frequency of acceleration coefficients [25].

frequencies of the acceleration coefficients differ, it is possible to illustrate the different character of the high-quality road (highway) and the lower quality road (road paved with granite blocks).

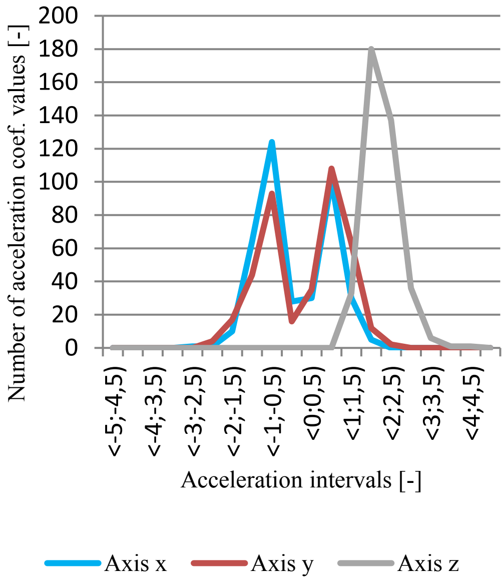


Fig. 6. Dataset 3 – frequency of acceleration coefficients [25].

This conclusion can be demonstrated by the number of intervals in which the values of the coefficients of acceleration in the individual axes fall. While for dataset 1 it is 6 in the x-axis, 8 in the y-axis and 4 in the z-axis, respectively 7, 8 and 4 for dataset 2, on lower quality road it is for the dataset 3 in the x-axis 10, in the y-axis 10 and in the z-axis 7, respectively 9, 11 and 6 for dataset 4.

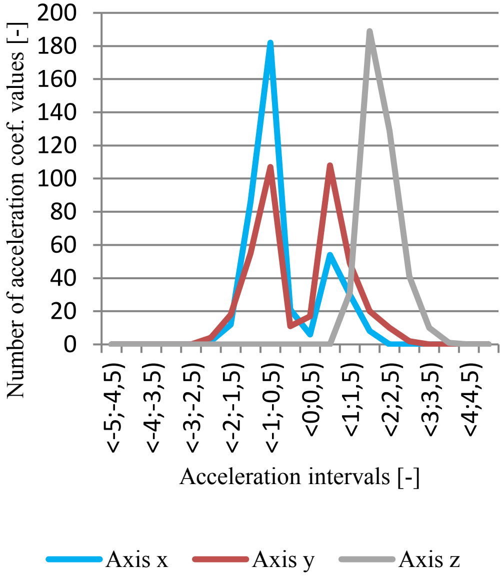


Fig. 7. Dataset 4 – frequency of acceleration coefficients [25].

2.5 Comparison of Securing Forces

Using the measured data – values of acceleration coefficients, the inertia forces acting on the fastening system (fastening straps) were calculated. The calculated inertia forces represent either a theoretical (based on normatively determined acceleration coefficients) or a practical requirement for a fastening system (in this case lashing capacity of the fastening strap). Based on the measured data and the basic objective is the practical application of the evaluation of the transport experiment, the calculated values of the inertia forces for each axis and every second of transport shall correspond to the required securing forces developed by the fastening system. For the fastening strap it is its lashing capacity (LC).

In order to calculate the magnitude of the inertia forces and the corresponding securing forces, a securing cargo that is standard on the vehicle type (T-810) is selected. Commercially available textile fastening straps without information about lashing capacity are used for securing. In practical application of the results, the lashing capacity would be determined from the required locking force as: nLC, where n is the number of fastening straps used.

The securing has been constructed based on the following assumptions:

- the securing calculation is based on the placement of two pallet units of 1,200 × 800 × 1,600 mm each and weight 1,000 kg (total weight of the model load is m = 2,000 kg),
- the pallet units are placed side by side (no gap), transversely to the direction of travel of the vehicle,
- the specific model attachment also corresponds to the angle between the strap and the plane of the loading area of the vehicle $\beta = 88.75°$, which is based on the loading width of the vehicle (see Fig. 8),
- standard textile fastening strap with Top-Over Lashing method is used for fastening; the number of straps (n) of given LC is left as a parameter,
- the friction coefficient for wood-plywood is used as $\mu = 0.3$ and the safety coefficient for the x-axis: $f_{s(x)} = 1.1$ and for the y-axis: $f_{s(y)} = 1.25$.

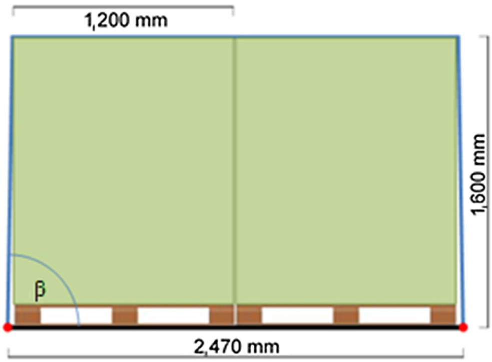


Fig. 8. Model of securing on T-810, own.

Statistical equality tests are used to compare datasets with each other and the calculated securing force based on normative values of acceleration coefficients for two basic:

- mean values compliance test,
- variance compliance test,

and two additional parameters:

- probability of exceeding the "normative" limit,
- the probability of double exceeding the "normative" limit.

Statistical equality tests are performed analogously to the previous tests on two parameters. It includes determination of upper bound, lower bound and parameter estimation. From these limits it is possible to determine not only whether the monitored datasets differ statistically significantly, but also the differences between the "magnitude of deviations".

Statistical equality tests are again performed at significance level $\alpha = 0.05$.

In accordance with EN 12195-1:2010, the securing forces (F_x, F_y) are calculated, which at the same time correspond to the expected magnitude of inertia forces acting on the load, resp. fastening strap [20]:

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

$$F_y = \frac{\left(c_y - \mu \cdot c_z\right) \cdot m \cdot g}{2n \cdot \mu \cdot \sin\ \alpha} \cdot f_s \quad [N] \tag{2}$$

With respect to model parameters that are the same in all four cases (for all datasets), the values of the "normatively determined" securing forces are as follows: $F_x = 17{,}989$ N and $F_y = 12{,}265$ N. In general, isolated exceedances are not considered to be a major problem. Frequent exceedances of these values have an impact on the service life of the fastening means, in this case the fastening straps. However, if this is a very common phenomenon in a given transport and the mean value (usually using the arithmetic mean or median) exceeds the "normatively determined" values of the securing forces, the impact on the strap's service life is essential and there is a risk of damage to the fastening strap, resp. partial components (e.g. ratchets, end components). If the mean value exceeds the double of "normatively determined" values of the securing forces, this is already a risky method of securing. If exceeding is triple, there is a risk of breaking the strap and the situation can be considered potentially dangerous in relation to cargo securing.

The values of the securing forces are given in Table 11 for an overview, including the securing forces based on the normatively determined acceleration coefficients (formally designated F_{xn}, F_{yn}) according to EN 12195-1:2010.

Table 11. Values of securing forces.

Characteristics	μ_i			
Dataset	Forces			
	F_{xi}	F_y	F_{xn}	F_{yn}
Dataset 1	30,363	19,820	17,989	12,265
Dataset 2	31,623	23,794	17,989	12,265
Dataset 3	34,606	35,944	17,989	12,265
Dataset 4	43,441	40,455	17,989	12,265

Source: Modified [25].

It is apparent from Table 11 that, due to the existence of a large number of extreme values in the set, the arithmetic means values are high and in all cases exceed the values of the securing forces resulting from the normatively set acceleration coefficients. The worst situation is in the last dataset (d_4), when the vehicle generated the greatest shocks compared to other datasets and the mean value exceeded the "normatively determined" values of the securing forces 2.4 times in the x-axis and resp. 3.3 times in the y-axis. Especially in the y-axis, the values of inertia forces (shocks) can be considered extreme and the requirements for the magnitude of the securing forces are also high, which is also related to the probability of exceeding (π_i) resp. double exceedance (γ_i) of the "normatively determined" values of the securing forces (see Table 12).

Table 12 shows that for all datasets there are a large number of securing force values that exceed the limit foreseen in EN 12195-1:2010. From the given measurement result it is possible to easily deduce the probabilities of exceeding, respectively double exceeding of the "normatively determined" securing forces on the respective surface and in the respective direction on the tested route. The high probability of double exceeding the assumed magnitude of the securing forces in the respective axes is, in particular, alarming. The worst results are, according to the assumptions, in dataset 4, where the probabilities of exceeding the "normatively determined" securing forces in both axes are greater than 75% and in case of double exceeding of more than 61%.

Table 12. Probability of exceeding, respectively double exceeding of the standard.

Characteristics	π_i		γ_i	
Dataset	Forces			
	F_x	F_y	F_x	F_y
Dataset 1	0.7484	0.4203	0.5237	0.3273
Dataset 2	0.6888	0.5299	0.5950	0.3673
Dataset 3	0.6117	0.7107	0.4898	0.5305
Dataset 4	0.8005	0.7581	0.6683	0.6110

Source: Own.

In terms of the interpretation of the results, it can be stated that such a number of exceedances will have a significant impact on the choice of the method of fastening, resp. lashing capacity of the strap. If the lashing capacity corresponding to EN 12195-1:2010 were chosen, there is a high probability that the fastening straps would be minimally damaged during transport if they would not break at the moment of extreme values (for dataset 4, the maximum determined values are F_x = 117,830 N and F_y = 133,407 N). Although these are isolated extreme values (the highest calculated values using experimentally measured acceleration coefficients), the model 2 tonne load at this time "behaves" as 5.89 t, resp. 6.67 t heavy load.

Furthermore, by means of statistical equality tests, a comparison of individual datasets is performed using arithmetic mean and variance. As an additional parameter the probability of exceeding, resp. double exceeding the assumed values of the securing forces is used (see Table 13). This is demonstrated on the one hand by using primary data (values of acceleration coefficients) and on the other hand by using calculated securing forces which correspond to real acting magnitudes of inertia forces.

For the additional parameters (probabilities of exceeding or double exceeding the assumed values of the securing forces), these are only valid for d_1–d_4 and d_2–d_4. Also in the other comparisons resulting from Table 13, it can be observed that there is a large

Table 13. Statistical equality tests – securing forces.

Confidence interval for	Inertial force values							
	F_x				F_y			
$d_1?d_2$	σ_1/σ_2	$\mu_1-\mu_2$	$\pi_1-\pi_2$	$\gamma_1-\gamma_2$	σ_1/σ_2	$\mu_1-\mu_2$	$\pi_1-\pi_2$	$\gamma_1-\gamma_2$
LB	0.850	–2,557	0.025	–0.109	0.909	–5,562	–0.148	–0.076
UB	0.947	39	0.094	–0.033	1.013	–2,386	–0.072	–0.004
PE	0.897	–1,259	0.060	–0.071	0.960	–3,974	–0.110	–0.040
$d_1?d_3$	σ_1/σ_3	$\mu_1-\mu_3$	$\pi_1-\pi_3$	$\gamma_1-\gamma_3$	σ_1/σ_3	$\mu_1-\mu_3$	$\pi_1-\pi_3$	$\gamma_1-\gamma_3$
LB	0.553	–7,025	0.083	–0.023	0.616	–19,325	–0.348	–0.259
UB	0.649	–1,460	0.191	0.090	0.723	–12,923	–0.243	–0.147
PE	0.600	–4,243	0.137	0.034	0.669	–16,124	–0.295	–0.203
$d_1<d_4$	σ_1/σ_4	$\mu_1-\mu_4$	$\pi_1-\pi_4$	$\gamma_1-\gamma_4$	σ_1/σ_4	$\mu_1-\mu_4$	$\pi_1-\pi_4$	$\gamma_1-\gamma_4$
LB	0.650	–15,474	–0.098	–0.198	0.631	–23,750	–0.388	–0.338
UB	0.762	–10,682	–0.006	–0.091	0.739	–17,520	–0.288	–0.229
PE	0.705	–13,078	–0.052	–0.145	0.684	–20,635	–0.338	–0.284
$d_2?d_3$	σ_2/σ_3	$\mu_2-\mu_3$	$\pi_2-\pi_3$	$\gamma_2-\gamma_3$	σ_2/σ_3	$\mu_2-\mu_3$	$\pi_2-\pi_3$	$\gamma_2-\gamma_3$
LB	0.617	–5,788	0.023	0.049	0.642	–15,354	–0.238	–0.219
UB	0.723	–178	0.131	0.161	0.753	–8,946	–0.134	–0.108
PE	0.669	–2,983	0.077	0.105	0.697	–12,150	–0.186	–0.163
$d_2<d_4$	σ_2/σ_4	$\mu_2-\mu_4$	$\pi_2-\pi_4$	$\gamma_2-\gamma_4$	σ_2/σ_4	$\mu_2-\mu_4$	$\pi_2-\pi_4$	$\gamma_2-\gamma_4$
LB	0.725	–14,241	–0.158	–0.126	0.657	–19,779	–0.278	–0.298
UB	0.849	–9,396	–0.065	–0.020	0.770	–13,542	–0.178	–0.189
PE	0.786	–11,819	–0.112	–0.073	0.712	–16,661	–0.228	–0.244
$d_3?d_4$	σ_3/σ_4	$\mu_3-\mu_4$	$\pi_3-\pi_4$	$\gamma_3-\gamma_4$	σ_3/σ_4	$\mu_3-\mu_4$	$\pi_3-\pi_4$	$\gamma_3-\gamma_4$
LB	1.064	–12,291	–0.251	–0.246	0.927	–8,692	–0.104	–0.149
UB	1.296	–5,380	–0.127	–0.111	1.129	–330	0.019	–0.012
PE	1.174	–8,836	–0.189	–0.178	1.023	–4,511	–0.042	–0.081

PE – parameter estimation
LB – Lower 95% confidence interval
UB – Upper 95% confidence interval
green – statistically significant difference (α = 0.05)
white – no statistically significant difference was found
orange – opposite inequality has been found
Source: Own.

number of extreme values in the dataset 4, partly also when compared to measurements on the same route (surface) in the opposite direction.

The results of statistical equality tests show that at the significance level $\alpha = 0.05$ there was a difference between the monitored surfaces for the two basic parameters, i.e. there is a statistically significant differences between the datasets d_1–d_3, d_1–d_4, d_2–d_3 a d_2–d_4. It can be stated that the investigated vehicle T-810 generates on road paved with granite blocks in average more shocks even at about half the speed.

The speed of the vehicle has not been determined, but corresponds to the normal speed corresponding to the surface and other conditions (e.g. weather), while observing the general principles of driving safety.

Assuming the creation of a model that compares transport on the surfaces surveyed at the same speed, the results would be different, but would not correspond to the reality and common principles of cargo transport.

The main aim of the chapter is to present practical recommendations for securing and transporting cargo, e.g. in military conditions or for the needs of the Integrated Rescue System and emergency supplies.

3 Results and Discussion

On the basis of these comparisons, it is obvious that even at a lower average speed (about half) there is a statistically significant difference between the tested roads at the significance level $\alpha = 0.05$. This conclusion applies to both tested basic descriptive characteristics (mean values in absolute values as well as variance of values of acceleration coefficients in all three axes). The same conclusion applies to the two basic parameters when comparing the respective securing forces.

It can be concluded that the T-810 vehicle generates on lower quality road (third class road) in average greater shocks (higher values of acceleration coefficients) even at about half the average transport speed. At higher speeds on a lower quality road, even greater differences in shocks can be expected. Generated shocks can be quantified as inertial forces that act not only on the cargo but also on the vehicle and the driver.

The graphical comparisons show a different distribution of values for each type of road. Primarily the graphical view of their variance in single intervals of 0.5 g differs significantly. Whereas for dataset 1 and 2 there is an average variance at 6 intervals, for datasets 3 and 4 it is almost at 9 intervals.

The results of comparing the datasets with the primary data are also confirmed by the calculated requirements for the magnitude of the securing forces and their comparison between individual datasets. Obviously, the T-810 vehicle generates generally higher inertia values than predicted, which increases the requirement for the securing forces of the respective fastening system (in this case the lashing capacity of the fastening straps used).

4 Conclusions

Shocks during transport affect the vehicle, the load and the driver. Chapter analyzed their influence on the freight, resp. on the load securing system. Based on the results, it can be stated that in real conditions the expected values of acceleration coefficients, resp. sizes of securing forces according to EN 12195-1:2010, are often exceeded. This happens not only on lower-quality roads, but also on high-quality roads, where higher speed is expected. According to the above mentioned norm, a suitable method of securing the load is chosen and if the assumptions in it do not correspond to reality in some cases, the securing system may be insufficient in terms of the required securing forces or completely unsuitable. Insufficiently or improperly secured cargo is not only a risk for the cargo itself, but also represents secondary risks such as damage to the vehicle, other technical means on the vehicle, cause a traffic accident involving injury, damage to the environment or other property damage [22].

The results of the analysis presented by the chapter can be mainly used to optimize the fastening of cargo by choosing a more suitable fastening system or fasteners with the corresponding lashing capacity. Lashing capacity must correspond to actual shocks (the magnitude of the acceleration coefficients, respectively resulting inertial forces), rather than simply theoretical assumptions of the standards.

The results show that, although conclusions can be drawn from the statistical evaluation of primary data (values of acceleration coefficients in individual axes), the real values of the inertia forces acting on the load (vehicle, driver) may exceed the "normatively" determined magnitude of securing forces even more. While the extremes in the x and y axes (the highest values in the absolute value) were measured "only" $c_x = 2.3$, resp. $c_y = 2.7$, which is 2.9 times, respectively 4.5 times the normative limit, for the securing forces it is even almost 6.6 times, resp. 10.9 times the expected magnitude of inertia forces.

A specific area of transport is the shipping of dangerous items, especially those that are directly affected by the shocks. These primarily include various types of explosives [23], that are transported by the army using their own or contracted vehicles.

In further research, the spectral analysis enables to transform the data (signal) of the time series into a frequency domain, which allows examination of other aspects of transport – cargo securing [9].

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