CARGO SECURING – COMPARISON OF DIFFERENT QUALITY ROADS

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Abstract

The article deals with the subject of the impact which road surfaces have onto cargo and the securing of cargo against shocks during road transport. The applicability of the key EN 12191-1:2010 standard is discussed, not only for common conditions, but also for specific transport conditions on low-quality road surfaces. Part of the article involves carrying out a transport experiment on a road paved with granite blocks and on a highway, from which data on the impact of shocks on cargo (acceleration coefficients values) were obtained. The data were statistically evaluated and compared to the normatively determined values of these acceleration coefficients. A parametric statistical analysis (two-sample t-test) was used to compare the values of the acceleration coefficients from the two types of surfaces. The analysis conducted shows statistically significant differences between the data measured on the road paved with granite blocks and on the highway. Using correlation analysis, the dependence of the acceleration coefficient values and inertial forces affecting cargo during transport were verified. For the relevant axes (x – longitudinal and y – transverse), a very strong correlation was found.

Keywords: transport, cargo securing, acceleration coefficient, inertial force, parametric methods, two-sample t-test

INTRODUCTION

Although cargo securing in road freight vehicles is not a new issue, a number of shortcomings occurs in this area. The main shortcomings include above all the link with road traffic accident rates, or the event of traffic accidents caused by incorrect or insufficient cargo securing. Within the European Union, it is estimated that up to 25% of all accidents caused by truck drivers are caused by improper cargo securing (EC DGET, 2014).

The Automotive Manufacturers and Importers Association (APIA) in cooperation with the ČESMAD Bohemia association organized a conference where other alarming numbers were heard. Every third day, a truck accident occurs due to an inappropriate cargo securing in the Czech Republic (CR). Traffic accidents, however, can only be considered as the tip of the iceberg, as it
was found during inspections on Czech roads that almost half of all cargo was not secured properly (SISA/ČESMAD BOHEMIA, 2018).

The DEKRA company reports an analogous number, although only in the segment of vehicles over 12 t (DEKRA, 2016). A shortcoming in the statistics is the monitoring of the technical causes of traffic accidents with different internal classifications. In 2017 the “improper stowage of cargo” caused almost 30% of accidents caused by technical defects in the CR (POLICE OF THE CR, 2018). The overloading of trucks is a related problem, where, according to data from the Road Transport Services Centre established by the Ministry of Transport of the Czech Republic, almost half of the vehicles were overloaded during weight checks (ROAD TRANSPORT CENTER, 2014).

Shortcomings in the area of cargo securing can be divided into:

- Deliberate: primarily for economic reasons, such as overloading vehicles, choosing an insufficient number of fastening devices, or using old and damaged fasteners.
- Caused by negligence: primarily due to the lack of knowledge of the relevant regulations and requirements on fastening the cargo, including the choice of suitable fasteners.
- Unintentional: that is, when the worker responsible for loading the cargo distributes the fasteners in good faith in accordance with the known regulations and requirements.

Based on the list above, it can be stated that the first two problems are primarily those of management – motivation and supervision over subordinates’ activities. The last problem is instead a transport-technical one, where for the purpose of correct cargo securing, it is necessary to know the parameters of transportation before securing is deployed. Such parameters include knowing the (assumed) magnitude of the inertial forces affecting cargo during transport. These can be determined using normative values of acceleration coefficients on individual axes (x, y and z), however this is a theoretical assumption based on empirical studies carried out in the past when the parameters of the transport system were different (e.g. vehicles, road surfaces). A more laborious and time-consuming procedure is the experimental detection of shocks (acceleration coefficient values) during transport under similar conditions using data loggers. Such measurements, ceteris paribus, assist in choosing the appropriate load-securing methods for transportation under similar conditions.

Such an experimental approach is of importance in cases where realistically measured shocks (magnitude of the acceleration coefficients) do not correspond with the normative values of the acceleration coefficients according to EN 12195-1:2010 (EN 12195-1:2010).

The article further focuses on the last area: unintentional non-compliance with the requirements of cargo securing. In such cases, an improvement in the human management system would not result in the desired effect because the problem is the absence of relevant data that is necessary either for software processing of the cargo securing plan, or for a manual solution. On the basis of pre-research, significant deviations were found, especially under specific conditions – on low-quality roads (Vlkovský et al., 2017; Vlkovský et al., 2018). In connection with the accident rate, it is also possible to quantify the impact of improper or insufficient cargo securing economically in the form of social loss caused by death or injury to persons and property losses (Vlkovský, Veselik and Grzesica, 2018).

These impacts may be significantly greater during the transport of dangerous goods. In such cases, it is not possible to speak of a higher likelihood of an accident, but of higher impact on persons, technology, infrastructure, and the environment. In the context of the above, the likelihood of a traffic accident will be higher on low-quality roads (see Risk Matrix in Fig. 1).

The transport of dangerous goods on low-quality roads is carried out by, for example, the military (ammunition, fuel, etc.) or farmers (pesticides, disinfecting chemicals, diesel, pressure cylinders, etc.), (Walter, 2018).

Fig. 1 shows that the transport of dangerous goods on low-quality roads would, without other measures, appear in the red part of the risk matrix (signifying “intolerable”). The impact of dangerous goods on persons, technology, infrastructure and the environment in a case of a traffic accident can be mitigated by complying with the requirements of the European Agreement on the International Carriage of Dangerous Goods by Road (ADR, 2017). Such experiments include a requirement on a vehicle’s technical condition that can reduce the likelihood of a road accident. During transport on low-quality roads, it can be assumed that with a greater impact of shocks onto a vehicle and cargo (Grzesica, 2018), the likelihood of a traffic accident increases hypothetically. This risk will be all the greater if the input parameters for choosing the securing method do not correspond with the given type of a transport route. The values
The issue of freight transport is the area of road transport, which is based on a wide range of general regulations, as well as specific manuals covering the transport of specific commodities. In accordance with the standard EN 12195-1:2010 (EN 12195:1-2010), EN 12195-2:2000 (EN 12195-2:2000) is used for the tested method of fastening with the aid of fastening straps. For correct fastening it is necessary to know the capacity of the load-bearing anchoring points, which is covered by EN 12640:2000 (EN 12640:2000), and the construction of the trucks or semi-trailers and trailers according to EN 12642:2001 (EN 12642:2001). Instructions of the Association of German Engineers VDI 2700:2009 (VDI 2700:2009) are applicable too.

The principles of proper cargo securing are further elaborated by other multinational institutions, in particular the European Best Practice Guidelines on Cargo Securing for Road Transport (UNECE, 2014) or the IMO/ILO/UNECE Code of Practice for Packing of Cargo Transport Units (CTU Code, 2014), or focused on dangerous goods – European Agreement Concerning the International Carriage of Dangerous Goods by Road (ADR, 2017), or for abnormal goods – Road Safety: Best Practice Guidelines on Cargo Securing and Abnormal Transport (EC DGET, 2016). These standards, manuals and documents are further elaborated by specific multinational companies, reflecting the transport of commodities that are the subject of their businesses. Several monographs are dedicated to the issue of cargo securing. It is worth mentioning T. Lerher’s book Cargo Securing in Road Transport Using Restraining Method with Top-Over Lashing, where the author discusses some general rules of road cargo securing with particular focus on top-over lashing (Lerher, 2015). The monograph of T. Lerher builds on the book by G. Grossman and M. Kassman on Safe Packaging and Load Securing in Transport, who present in their book the methods of cargo securing, including top-over lashing models using fastening straps (Grossman and Kassman, 2018).

The specifics of oversized cargo are then discussed by W. Galor and a team of authors in his book Carriage and Securing of Oversized Cargo in Transport (Galor et al., 2011) or in the paper (Vrabel et al., 2018). Articles dealing with the area of cargo securing are usually focused on the issue of software simulations, e.g. (Zong et al., 2017) or (Neumann, 2015). The discussion on the data source for models (e.g. acceleration coefficients) appear rather sporadically, e.g. (Zámečník et al., 2017 or Jagelčák, 2017).

**MATERIALS AND METHODS**

To obtain the necessary data for the statistical analysis, a transport experiment was conducted with the medium freight terrain vehicle Tatra 810-V-1R026 13 177 6 × 6.1R (hereinafter “T-810”) (Kolmaš, 2007) on a highway and a low-quality road (road paved with granite blocks) with a mileage of less than 45,000 km. The transport experiment was carried out with the T-810 without load.

As a measuring device a three-axis accelerometer with data logger and OMEGA – OM-CP-ULTRASHOCK-5 calibration certificate with the measurement range ±5 g was used to record the shocks (acceleration coefficient values) on each of the three axes (x – longitudinal, y – transverse and z – vertical) every second. The measuring device was placed on the central steel frame of the vehicle body.

The measurements were made under optimal climatic conditions, the transport routes were...
dry, no precipitation was recorded during the measurements and the visibility was excellent. The outdoor temperature ranged from 7 to 11 °C. The measurements were also not influenced by traffic jams or slow-moving vehicles.

The first data set \(d_1\) contains data (acceleration coefficient values) from the transport on the highway section Brno – Vyškov, where the data set consists of 3,804 values (1,268 for each axis). The average speed of transport was 76.66 km.h⁻¹. The measurements were also not influenced by traffic jams or slow-moving vehicles.

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The second dataset \(d_2\) contains the acceleration coefficient values collected on the road paved with granite blocks on the section Dědice (training area) – Vyškov and consist of 1,203 values (401 per axis). The average transport speed was roughly half that of the first dataset: 38.60 km.h⁻¹.

The aim of the article is to statistically evaluate the two measured datasets \(d_1\) and \(d_2\) and consequently compare them to the values of normatively determined values of acceleration coefficients and (theoretical) values of the inertial forces obtained from the calculations according to the relationships of the standard (EN 12195-1, 2010).

Before the statistical analysis, normality tests were performed using skewness and kurtosis coefficients (Johnson and Wichern, 1992). The significance level was \(\alpha = 0.05\). The data normality was also verified using Q-Q plots and histograms. The Q-Q plots were drawn for acceleration coefficients in each of the three axes \((x, y, z)\). Although in some data sets the distribution of acceleration coefficients was not normal but symmetrical (which was verified by Q-Q plots, histogram and skewness coefficients) and included outliers, further analysis was carried out assuming normal distribution.

When comparing two independent data sets \(d_1\) and \(d_2\) from two normal distributions, both the match of variance \(\sigma_1^2 = \sigma_2^2\) and the match of mean values \(\mu_1 = \mu_2\) were tested (Neubauer et al., 2012). When testing the absolute values of mean values (arithmetic means of acceleration coefficient values on individual axes) were used, i.e. \(\mu_{x_{abs}}\) or \(\mu_{y_{abs}}\) because of the value distribution. Because the shocks oscillate around the value 0 except for the \(z\)-axis where the coordinate axis is shifted by 1 g and the measuring range is limited by the measuring device.

The comparison of the calculated arithmetic means of the absolute acceleration coefficient values and the inertial forces with the normative values is also shown graphically taking into account the value exceeding twice the normative values – see Tab. I.

Using the correlation analysis, specifically the Pearson correlation coefficient (Hendl, 2015), a statistical link between the acceleration coefficient values and the resulting inertial forces acting on the load was found. The values of inertial forces \(F_x\) and \(F_y\) are calculated (implicitly) from the tensile strength requirements of the lashing straps and the equality of the two forces:

\[
F_x = \frac{(c_x - \mu \cdot c_x) \cdot m \cdot g}{2n \cdot \mu \cdot \sin \alpha}, \quad [N],
\]

\[
F_y = \frac{(c_y - \mu \cdot c_y) \cdot m \cdot g}{2n \cdot \mu \cdot \sin \alpha}, \quad [N],
\]

where \(F_x\) is longitudinal, \(F_y\) transverse inertial force to the vehicle movement, respectively (see Fig. 2), \(c_x, c_y, c_z\) are the acceleration coefficients the individual axes, \(\mu\) is the coefficient of friction, \(m\) is the mass of the load, \(g\) is the gravity acceleration, \(f_s\) is the coefficient of safety for frictional lashing, \(n\) is the required number of lashing straps and \(\alpha\) is the angle between the lashing strap and the deck of the vehicle.

### RESULTS

It is clear from the statistical analysis of data sets that the relatively large number of acceleration coefficients exceeded the normative values stated in the standard EN 12195-1:2010, which are set

<table>
<thead>
<tr>
<th>Acceleration coefficients [–]</th>
<th>Inertial forces [N]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arithmetic mean</td>
<td>Median</td>
</tr>
<tr>
<td>(c_x)</td>
<td>(c_y)</td>
</tr>
<tr>
<td>(d_1)</td>
<td>0.601</td>
</tr>
<tr>
<td>(d_2)</td>
<td>0.916</td>
</tr>
</tbody>
</table>

I: The arithmetic means and medians of the absolute values of the acceleration coefficients for all axes and arithmetic means of inertial values for both datasets (values which exceed normative limits are highlighted in yellow, and the values which exceed normative limits by more than two are highlighted in red)
as follows: 0.8, 0.6 and 1.0 for the $x$, $y$ and $z$ axes, respectively. In data set $d_1$, the normatively set limits were exceeded in 20.61% of cases, and exceeded by a factor of two in 0.58% of cases. The excess was most common on the $y$-axis. In data set $d_2$, the normatively set limits were exceeded in 61.68% of cases, by a factor of two in 10.72% of cases. Also, the excess on $y$-axis prevailed, although the differences between axes were smaller than in the $d_1$ data set.

Tab. I shows the results of the descriptive statistics for the absolute acceleration coefficient values, specifically the arithmetic means and medians for the axes $x$, $y$ and $z$, for both datasets ($d_1$ and $d_2$). In addition, the table also includes the results of inertial forces values, which are essential for the choice of cargo securing system (not the value of acceleration coefficients). The magnitude of the inertial forces was calculated using formulas (1) and (2) and further normative limits ($F_{x}$ and $F_{y}$). Subsequently, the relevant values of inertial forces were calculated for both data sets (marked as $F_{x}$ and $F_{y}$ in Tab. I). It can be seen from Tab. I that the lowest arithmetic mean of the absolute values of the acceleration coefficients (0.601) was measured on the $x$-axis of the first data set. Contrarily, in the second data set, the highest arithmetic mean of the absolute values of the acceleration coefficients (2.005) was measured on the $z$-axis.

The descriptive statistics presented in Tab. I show that the data sets differ greatly. The average values of the inertial forces on the $x$-axis and $y$-axis were exceeded in both data sets, in $d_1$ even more than twice. In the second dataset, normatively set limits according to EN 12195-1:2010 were exceeded in five cases, where the excess reached almost 67% for the $y$-axis. In contrast, in $d_2$, the excess occurred only in two cases on the $y$-axis and the excess was relatively small – less than 7%. This is mainly due to the relatively low normative values of acceleration coefficients on the $y$-axis ($c_y$), which is based on greater risks when loosening the cargo in the direction transverse to vehicle motion. Both data sets will be subjected to detailed statistical analysis in next part of this article.

Because the measured data (the values of acceleration coefficients) were considered coming from normal distribution for all axes, a parametric two-sample $t$-test was used to evaluate both data sets. The test was performed for all three axes at a significance level of $\alpha = 0.05$. The results of the performed tests are shown in Tab. II. In the first column of this table, the relevant acceleration coefficients are listed. In the second column ($AH_{F_1}$), an alternative test hypothesis of variance match is shown. In column $F$, the test statistics of variance match test is shown. In the fourth column the alternative hypothesis of mean values match, and finally, the column denoted $t$ contains the test statistics of a mean values match test assuming heteroskedasticity.

The results of the two-sample $t$-test shown in Tab. II show that statistically significant differences exist between the two data sets at the significance level $\alpha = 0.05$ for the two tested statistics. These results point to the very different values of shocks generated on the highway ($d_1$) and on the road paved with granite blocks ($d_2$) despite the almost halved average speed of vehicles on low-quality roads.

Subsequent one-sided tests showed, at the significance level $\alpha = 0.05$, that for both monitored parameters (arithmetic mean of absolute...
values and variances), there is a statistically significant difference between both data sets on all three axes and for \( c_x, c_y, \) and \( c_z \), it is valid that the arithmetic means of absolute values are smaller for \( d_1 \) than for \( d_2 \) (\( \mu_1 < \mu_2 \)) or the variances of values are smaller for \( d_1 \) than for \( d_2 \) (\( \sigma_1^2 < \sigma_2^2 \)).

Considering the laboriousness of determining the inertial values especially for practice, the extent of correlation between acceleration coefficients (\( c_x, c_y, c_z \)) and the relevant inertial values (\( F_{xi} \) and \( F_{yi} \)) is further calculated. For the calculation the Pearson correlation coefficient was used. First, however, a graphical comparison was made, the values of the inertial forces were plotted on the horizontal axis and the corresponding acceleration coefficients were plotted on the vertical axis. In both cases, it was shown that the given pairs show a linear trend – see Fig. 3. Since the individual graphs well document the linear trend, the statistical relationship between the acceleration coefficients and the resulting inertial forces acting upon the cargo was assessed with the Pearson correlation coefficient as well. Its values are shown in Tab. III.

![Graphs showing correlation analysis](3: Correlation analysis between \( c_x \) and \( F_{xi} \) (left figure) and \( c_y \) and \( F_{yi} \) (right figure))

Fig. 3 and the Pearson correlation coefficient values in Tab. III show a very strong dependence between the corresponding acceleration coefficients and the values of inertial forces acting upon cargo. The values of the Pearson correlation coefficient range from 0.990 to 0.997. From such a strong dependence between the measured coefficients and the calculated inertial values, it can be concluded that the results can already be interpreted from the acceleration coefficient analysis (measured shocks). Nevertheless, the analysis shows a difference in the extent of exceeding the normatively set limits for the acceleration coefficient and the subsequent difference contrary to the inertial forces by using the normatively determined acceleration coefficient values.

### II: Results of a two-sample t-test for all axes

<table>
<thead>
<tr>
<th>Acceleration coefficients [-]</th>
<th>( AH_F )</th>
<th>( F )</th>
<th>( AH_t )</th>
<th>( t )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( c_x )</td>
<td>( \sigma_1^2 \neq \sigma_2^2 )</td>
<td>0.163*</td>
<td>( \mu_1 \neq \mu_2 )</td>
<td>–18.406*</td>
</tr>
<tr>
<td>( c_y )</td>
<td>( \sigma_1^2 \neq \sigma_2^2 )</td>
<td>0.256*</td>
<td>( \mu_1 \neq \mu_2 )</td>
<td>–15.833*</td>
</tr>
<tr>
<td>( c_z )</td>
<td>( \sigma_1^2 \neq \sigma_2^2 )</td>
<td>0.174*</td>
<td>( \mu_1 \neq \mu_2 )</td>
<td>–17.102*</td>
</tr>
</tbody>
</table>

* *indication of the values of relevant statistics, when the related null hypothesis was rejected at the 5% significance level

### III: Correlation between acceleration coefficients and the corresponding inertial values

<table>
<thead>
<tr>
<th>( F_{xi} )</th>
<th>( F_{x2} )</th>
<th>( F_{yi} )</th>
<th>( F_{y2} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( c_{x1} )</td>
<td>0.995</td>
<td>0.990</td>
<td>–</td>
</tr>
<tr>
<td>( c_{y1} )</td>
<td>–</td>
<td>–</td>
<td>0.997</td>
</tr>
</tbody>
</table>
DISCUSSION

It follows from the performed analysis that on the examined T-810 vehicle, the shocks generated on the high-quality road (highway) and the lower-quality road (paved with granite blocks) differ in a statistically significant way. On the basis of the one-sided test, it is clear that the cargo securing requirements will be higher in terms of lashing capacity during cargo transport on granite-block-paved roads. It can be assumed that the similar conclusion will apply to other types of vehicles too. The key impact of the results is then on vehicles which operate on lower-quality roads (military, integrated rescue system, farmers, etc.).

The benefit may also be seen in an increase in the safety of the cargo securing during the transport of dangerous goods, where the risk arising from improper or insufficient fastening of the load may be significantly higher. In military conditions, is spoken primarily of the transport of ammunition and fuel in multinational operations. In the case of farmers, transport of pressure cylinders, fuels, pesticides, disinfection chemicals or hazardous waste from agricultural production are the most dangerous. Potential accidents can cause damage to the health of persons, the vehicle and other technical equipment and last but not least the environment.

Also, the impact of shocks and vibrations onto the vehicle and driver is a relatively independent area. The vehicle may experience faster wear due to shocks and vibrations, which can shorten the maintenance period or cause more frequent occurrence of defects, which must be removed at extra cost. The impact on drivers is mainly in the health area, where shocks and vibrations can cause fatigue, reduced attention span, longer reaction time (Buscházy et al., 2016), impaired perception and reduced performance as a result of muscle, joint, tendon and other pain and thus negatively affect cargo securing in general.

CONCLUSION

Statistical analysis of data sets from the transport experiment had led to important findings regarding the existence of statistically significant differences between the measured values of shocks generated on highways and roads paved with granite blocks, which can be considered as third-class roads. This conclusion has impacts mainly on completely different requirements for cargo securing on roads of different quality (that is, different classes of roads).

The basic evaluation of the measured values of the acceleration coefficients show significant differences in the number of exceedances of the prescribed values during the given transports. On the highway, the normatively set limits were exceeded in 20.61% of cases, and exceeded by a factor of two in 0.58% of cases. However, in third-class road, normatively set limits were exceeded in 61.68% of cases, by a factor of two in 10.72% of cases. This implies much higher likelihood of emergencies during transport (cargo release, accidents, etc.) on the third-class road despite a significantly lower transport speed. The results of the performed t-test indicate a statistically significant differences at a significance level $\alpha = 0.05$ between the two types of road surfaces in both monitored parameters (arithmetic means and variances).

The correlation between the experimentally determined values of the acceleration coefficients and the resulting inertial forces is verified for practical use. The Pearson correlation coefficient ranges from 0.990 to 0.997, indicating a strong linear dependence. Thus, from the experimentally determined the acceleration coefficients values, conclusions can be made without acceptable inertial calculations with adequate accuracy.

Changes in the Czech transport system, especially after 1989, are evident. It is not only infrastructure, but also means of transport and increased transport capacity. The poor condition of many transport routes in the Czech Republic can result not only in increased repair costs and shortened vehicle life-cycles (Binar et al., 2017), but also in increased accident rates, which can be discussed in an economic context (Vlkovsky, Veselik and Grzesica, 2018).

Further research will focus on the analysis of case studies for other relevant vehicle types (e.g. T-815, including container carriers), types of transport routes (road classes) or for other modes of transport. The influence of shocks on cargo securing method or road safety as such would be appropriate to take into account also for transport optimization tasks and models, whether in military conditions (Stodola, 2018) or in other areas such as agricultural production (Kučera
and Krejčí, 2013 or Košíček et al., 2012). The aim of every transport is above all to transport cargo – that is, safely and nowadays it is becoming increasingly important at what cost. Damage to cargo, other technical equipment, infrastructure, environment or even injury or death of persons is a key issue which is best dealt with by prevention. This means by appropriate and sufficient cargo securing, including the proper training of persons responsible, especially loading teams and drivers.

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