IOP Conference Series: Materials
Science and Engineering

PAPER • OPEN ACCESS

Impact of Shocks on Cargo Securing During the Road Transport

To cite this article: Martin Vlkovsky *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **603** 032045

IOP Conf. Series: Materials Science and Engineering **603** (2019) 032045 doi:10.1088/1757-899X/603/3/032045

Impact of Shocks on Cargo Securing During the Road Transport

Martin Vlkovsky [1], Tomas Binar [1], Jiri Svarc [1], Petr Nemec [1], Katerina Bucsuhazy [2]

[1] University of Defence, Kounicova 156/65, 662 10 Brno, Czech Republic
[2] University of Technology, Purkyňova 464/118, 612 00 Brno, Czech Republic

martin.vlkovsky@unob.cz

Abstract. The paper deals with the impact of shocks on cargo securing during the road freight transport. Commonly used methods of cargo securing do not take into account the different quality of roads, therefore the cargo securing doesn´t have to comply with principles of safe fastening. The paper highligths the different values of shocks and inertia forces on different quality roads (highway and 3rd class road) based on data of conducted transport experiments. The resulting shocks (values of acceleration coefficients) are statistically significantly higher on 3rd class road than on highway even at half average speed. The optimization of calculation using acceleration coefficients and their correlation with the resulting inertia forces is included in separated part. The output of the paper is a methodical procedure to optimize the cargo securing during the road transport.

1. Introduction

In today's globalized world, freight transport is playing an increasingly important role. Road transport plays a key role in ensuring door-to-door concepts not only individually but also in combination with other modes of transport - within multimodal transport. Within the European Union (EU), a total of 14,608,049,000 tonnes of cargo were transported in 2017 [1]. The number of people killed as a result of a road accident (up to 30 days after the accident) was 25,300, with only 8% of them on motorways, another 37% in built-up areas and the largest portion – 55% on other roads [2]. Over the past 10 years, the proportion of truck accidents of the total number of accidents has been around 15% [3, 4], while it is estimated that up to 25% of all accidents caused by lorry drivers are caused by incorrect or insufficient cargo securing within the EU [5]. By simple calculation, it can be estimated that in 2017, almost 14,000 people were killed on other roads and of the total number of persons killed was, by qualified estimation, a little less than 1,000 during traffic accidents caused by improperly or insufficiently fixed loads. Although there has been a significant decrease in the number of people killed on the roads over the last ten years (2007-2017), (by almost 34%) [6] the number of people killed due to improper cargo securing is still a relatively large number (almost 4% of the total number). In addition to this, property damage, which is caused by accidents not leading to death or personal injury, must be added. The statistics do not include damage to property, environmental damage, etc. that occurred during cargo transport activities – such as loading / unloading / reloading, storage or off-road movement (within businesses, on local and utility roads).

The aim of the article is to point out one of the reasons for the lack of load securing due to the rigid approach of European standards (especially EN 12195-1:2010). The acceleration coefficients presented do not take into account changes in transport systems over several decades and do not distinguish between different quality of transport routes or other aspects of freight transport.

2. Material and Methods

2.1. Material

To prove the differences between the monitored characteristics of selected types of transport routes, and justification of the limited validity of the use of prescribed acceleration coefficients, the relevant transport experiments were performed on a Tatra 810-V-1R0R26 13 177 6×6.1R vehicle (hereinafter referred to as "T-810"). The transport experiments were carried out on the highway (Brno – Vyškov route) and 3rd class road (Vyškov – Březina). The average transport speed was about a half on the 3rd class road (see below).

Acceleration coefficients on individual axes (x – longitudinal, y – transverse and z – vertical) were used as the basic parameters for comparison. The three-axis accelerometer OMEGA – OM-CP-ULTRASHOCK-5 was used for the measurement with the measuring range $\pm 5g$, which recorded the vibrations every second of transport. In the transport experiment, the climatic conditions were optimal without precipitation, the surface of the roads was dry and the visibility was excellent. The outside temperature was around +9 ° C.

Two data sets (d_1, d_2) were obtained to perform statistical analysis. The dataset *d1* contains the values of the acceeration coefficients (shocks) for all axes (formally marked c_x, c_y a c_z), the number of values is 1,268 for each of the axes. The average transport speed in the first transport experiment (d_1) was 76.7 $km \cdot h^{-1}$. Similarly, in the data set d_2, 401 values are for each axis and the average transport speed in the second transport experiment was 38.6 $km \cdot h^{-1}$.

2.2. Methods

To test the measured sets (statistical hypotheses), the significance level $\alpha = 0.01$ and the following tests in the STAT1 environment were selected:

- a test of compliance of mean values,
- a test of compliance of variances [7].

Q-Q plots [8] were used to validate the normality of data sets before performing the tests. Part of the calculation is also ti determine the probability of exceeding the normatively set limits (π_i), including double exceeding the normatively determined acceleration coefficients (γ_i) for both data sets. For the calculation, the number of exceedances of normatively determined acceleration coefficients according to EN 12195-1:2010 on individual axes was used:

- $c_{xn} = 0.8$,
- $c_{yn} = 0.6$,
- $c_{zn} = 1.0$ [9],

where c_{xn}, c_{yn}, or c_{zn} are the prescribed values of acceleration coefficients in longitudinal direction, or transverse direction, or vertical direction in relation to the motion of the tested vehicle.

Two correlation coefficients are used to determine the correlation of the acceleration coefficients used in individual axis with the resulting values of inertia:

- Spearman's rank correlation coefficient (ρ)
- Kendall's concordance coefficient *(W)*.

Indexes according to the respective axes and datasets are used to mark the calculated inertia forces (F). Using the aforementioned two correlation coefficients, a correlation is found between c_x for both datasets (c_{x1}, c_{x2}) with inertia forces on the x-axis for a given dataset (F_{x1}, F_{x2}). Correspondingly, a correlation is found between c_y for both datasets (c_{y1}, c_{y2}) with inertia forces in the y-axis for a given dataset (F_{y1}, F_{y2}).

Inertia forces calculated using real-time acceleration coefficients on individual axes are calculated using the relations from EN 12195-1:2010 [9]:

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

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

3. Results and discussions

3.1. Results of acceleration coefficient analysis

Using Q-Q plots, the normality of experimentally determined data was graphically verified. The data showed minor deviations from normality, theoretical quantiles and empirical quantiles were approximately on one line [10]. A parametric two-sample t-test was used to evaluate both data sets. In all three axes, a t-test was performed at the significance level $\alpha = 0.01$ for two parameters: variance and arithmetic mean of the absolute values of the acceleration coefficients.

The result was the rejection of the null hypothesis of variance compliance, or arithmetic means of absolute values and acceptance of an alternative hypothesis. Thus, it was proved that there are statistically significant differences between the two data sets at the significance level $\alpha = 0.01$ for both tested parameters. These results point to the very different values of the shocks generated by the vehicle being monitored on the highway (d_1) and on the 3rd class road (d_2) despite the almost half the average speed of the vehicle on a lower-quality road.

Furthermore, analogically, one-sided tests were carried out on the same level of significance by means of which it was tested whether the monitored vehicle generates on the 3rd class road (d_1), even at half the average speed, higher shock values than when moving on the highway (d_2). The outcome of the one-sided tests was the conclusion that even at half the average vehicle speed, which corresponds to normal traffic conditions on a given type of traffic route, the T-810 generates more shocks on the 3rd class road than on the highway. The stated conclusions also demonstrate the probability of exceeding, or double exceeding the prescribed acceleration coefficients given in EN 12195-1:2010 – see Table 1.

Table 1. Probability of exceeding the normative limits (d_1, d_2).

Characteristics	π_i (exceeding the norm)			γ_i (double exceeding)		
Coef. / **Dataset**	c_x	c_y	c_z	c_x	c_y	c_z
d_1	0.0607	0.5505	0.0402	–*	0.0189	–*
d_2	0.6135	0.8504	0.4514	0.0424	0.2544	0.0274

Table 1 shows that the probability of exceeding the normatively determined acceleration coefficients in all three axes is significantly higher for the second data set, i.e. during transport by 3rd class road, even at about half the average transport speed. Especially for the x-axis and z-axis, there are differences.

In the case of double exceedances, the situation is similar, although in the case of the *x* and *z* axes, the situation when the normatively set limits were doubled during highway transport (d_1) is missing (the normative values in the *x* and *z* axes were not double exceeded in the transport experiment). The highest probability of double exceeding of the norm was recorded for d_2 on the *y*-axis, which is mainly based on the lowest normative value (c_{yn} = 0.6).

3.2. Results of analysis of inertia forces

The previous analysis needs to be supplemented by the calculation of inertia forces in the respective axes for the examined dataset ($F_{x1}, F_{x2}, F_{y1}, F_{y2}$), which actually acts on the fastener used – in this case the strap (and load). Already the comparison of mean values of inertia forces results in the same conclusions that were formulated above for the acceleration coefficients and the probability of exceeding the prescribed limits (see Table 2). Table 2 is also completed with theoretical inertia values in the respective axes using normatively determined acceleration coefficients (F_{xn}, F_{yn}).

Table 2. Arithmetic means of absolute values of acceleration coefficients and inertia forces at d_1, d_2

	Arithmetic means of absolute values						
	Acceleration coefficients [–]			**Inertia forces [N]**			
	c_{xi}	c_{yi}	c_{zi}	F_{xi}	F_{yi}	F_{xn}	F_{yn}
d_1	0.6012	0.6396	1.6381*	30,363	19,820	17,989	12,265
d_2	0.9155	0.9994	2.0047*	43,441	40,455	17,989	12,265

* The measuring device should shift the coordinate axis of the *z*-axis by 1*g*.

Table 2 shows that the values of acceleration coefficients on average exceed the normative limits according to EN 12195-1:2010 in 4 cases (c_{y1}, c_{x2}, c_{y2}, c_{z2}). The calculated values of inertia forces then exceeded the theoretical inertia values (F_{xn}, F_{yn}) in all cases, even twice in dataset 2. At first sight, the correlation of the inertia forces with the applied acceleration coefficients, which are part of the calculation, is evident (it will be verified algebraically using the appropriate correlation coefficients). Depending on the model and values used (eg. vertical lashing angle or friction factor), the resulting inertia forces may exceed the theoretical inertia forces even more than twice.

3.3. Correlation between acceleration coefficients and inertia forces

In the logistics and transport practice, drivers and loading groups cannot be expected to have sufficient knowledge of impact of inertia forces. The advantage here is the use of support software applications, which allow significant simplification for users. However, the drawback of these software supports is the lack of knowledge of the algorithms by which the vehicle is loaded, or the load secured. As another drawback we can consider the "non-standard" loading, i.e. the fixing of a specific load or the fixing of a load for transportation under"non-standard" conditions (eg. lower-quality roads). For the sake of simplicity, with the assumption of applying the article outputs in practice, it is only possible under certain assumptions to use the outputs from accelerometers (acceleration coefficient values). The basic requirement is to ensure cargo securing with the knowledge of the shocks (acceleration coefficients). Thus, a strong correlation is required between the respective acceleration coefficients and the calculated inertia values, which act on the load or the entire fastening system. The results of the calculated correlation coefficients are summarized in Tables 3 and 4.

Table 3. Correlation tests between acceleration coefficients and inertia forces (*x*-axis)

	c_{xi}	
	ρ	W
F_{x1}	0,9825	0,9002
F_{x2}	0,9939	0,9381

Table 4. Correlation tests between acceleration coefficients and inertia forces (*y*-axis)

	c_{yi}	
	ρ	**W**
F_{y1}	0,9875	0,9181
F_{y2}	0,9911	0,9307

Tables 3 and 4 show a very strong correlation between the magnitude of the respective acceleration coefficient and the value of inertia in a given axis. All coefficients used have values above 0.90 for both axes and both datasets. In the case of Spearman's correlation coefficient (ρ), the value is not less than 0.98 in either case.

4. Conclusions

The presented transport experiments show the importance of taking into account the type of transport route (not only the road but also the terrain) for cargo securing purposes. Especially in the case of lower-class roads, it is generally assumed that large shocks will occur despite a significantly lower transport speed. The use of EN 12195-1:2010 is not appropriate in general, which can be demonstrated experimentally, especially under off-road conditions [11, 12]. Failure to take into account the aforementioned specifics may result in the release of cargo, which may lead to a traffic accident, loss of property, and the lives or health of people [13].

The methodological approach used in the article makes it possible to easily and quickly take into account the empirically obtained values of shocks for other transports. Especially for transport companies that use a large fleet of vehicles and carry cargo on the same or similar routes, this approach can be considered beneficial. In addition, for transports that are specific (eg type of road, vehicle, cargo), this can significantly increase the safety of such shipments. For practical use, evaluation of past shipments can only be based on experimentally measured data (acceleration coefficient values) if the transport parameters are similar, as evidenced by the high correlation coefficients used. More complicated work with inertia forces is not necessary and therefore a worker with only basic cargo securing knowledge (driver, loading team worker, etc.) can enter the process.

The subject of further research will be the concept of basal vectors of acceleration coefficients for selected types of transport routes, which would be a guide for the choice of the fastening method. For lower-quality routes, the inclusion of the basal acceleration coefficient vector in determining (calculating) the required lashing capacity of the respective fastener would be crucial. Furthermore, it is possible to continue in the statistical analysis using advanced statistical methods, see [14, 15] and their application on data on the vehicle load during its transportation using the software and program products. The subject of the research is also the application of a different approach to data using spectral analysis [16], i.e. investigation of signal frequencies, not shocks per time unit.

Acknowledgment(s)

The paper was written with the support of the project of long-term strategy of organization development: ROZVOLOG: Development of Capabilities and Sustainability of Logistics Support (DZRO ROZVOLOG 2016–2020) funded by the Ministry of Defence of the Czech Republic.

References

[1] EUROSTAT, "*Goods Tranport by Road*." [online]. c2019. [vid. 2019-03-07]. Available at <https://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&language=en&pcode=ttr00005&plugin=1>.
[2] EUROPEAN COMMISSION, "*2017 Road Safety Statistics: What is Behind the Figures*." [online]. c2018. [vid. 2019-03-05]. Available at <http://europa.eu/rapid/press-release_MEMO-18-2762_en.htm>.

IOP Conf. Series: Materials Science and Engineering **603** (2019) 032045 doi:10.1088/1757-899X/603/3/032045

[3] EUROPEAN COMMISSION, "*Traffic Safety Basic Facts 2018.*" [online]. c2018. [vid. 2019-03-08]. Available at <https://ec.europa.eu/transport/road_safety/sites/roadsafety/files/pdf/statistics/dacota/bfs20xx_hgvs.pdf>.

[4] ACEA, "*Trucks and Vision-Related Accidents: Active Safety 50 % More Effective Than Direct Vision Cabs*." [online]. c2017. [vid. 2019-03-01]. Available at <https://www.acea.be/news/article/trucks-and-vision-related-accidents-active-safety-50-more-effective-than-di>.

[5] EUROPEAN COMMISION, "*European Best Practice Guidelines on Cargo Securing for Road Transport.*" [online]. c2014. [vid. 2019-02-15]. Available at <www.uirr.com/fr/component/downloads/downloads/ 302.html>.

[6] EUROPEAN COMMISSION, "*Annual Accident Report 2017.*" [online]. c2017. [vid. 2019-03-03]. Available at <https://ec.europa.eu/transport/road_safety/sites/roadsafety/files/pdf/statistics/dacota/asr2017.pdf>.

[7] J. Neubauer et al., "*Principles of Statistics: Applications in Technical and Economic Disciplines*," Grada, 2012.

[8] R. A. Johnson, D. W. Wichern, "*Applied multivariate Statistical Analysis*," Prentice-Hall International, 2007

[9] EUROPEAN COMMITTEE FOR STANDARDIZATION, "*EN 12195-1: Load Restraining on Road Vehicles – Safety – Part 1: Calculation of Securing Forces*," CEN, 2010.

[10] M. Vlkovský et al., "Cargo Securing During Transport Depending on the Type of a Road," *WMCAUS 2017 IOP Conference Series: Materials Science and Engineering*, 2017.

[11] M. Vlkovský et al., "Wavelet Based Analysis of Truck Vibrations during Off-road Transportation," *The 14th International Conference on Vibration Engineering and Technology of Machinery*, 2018.

[12] D. Grzesica, "Measurement and Analysis of Truck Vibrations during Off-road Transportation," *14th International Conference on Vibration Engineering and Technology of Machinery*, 2018.

[13] M. Vlkovský et. al., "Cargo Securing and its Economic Consequences," *Transport Means – Proceedings of the 22nd International Scientific Conference Part I*, pp. 129-135, 2018.

[14] P. Veselík, A. Dvorská, J. Michálek, "Half a year of co-located gaseous elemental mercury measurements: investigation of temporal changes in measurement differences," *Fresenius Environmental Bulletin*, vol. 26, no. 5/2017, pp. 3128-3137, 2017.

[15] M. Campulová et al., "Control Chart and Six Sigma Based Algorithms for Identification of Outliers in Experimental Data, With an Application to Particulate Matter PM10," *Atmospheric Pollution Research*, vol. 8, no. 4, pp. 700-708, 2017.

[16] D. Grzesica, P., Wiecek, "Advanced Forecasting Methods Based on Spectral Analysis," *WMCAUS: Procedia Engineering*, vol. 16, pp. 253-258, 2016.