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Analysis of Methods for Calculating Means of Securing Cargo

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Abstract

This article gives an analysis of the regulatory documents for securing cargo, the procedure for calculating the securing means. The authors investigated the prospects, advantages and disadvantages of the existing methods of securing cargo, proposed a calculation method for securing means using modern regulatory requirements. Based on the calculations and studies of cargo securing methods, a number of recommendations were proposed for further improvement of the calculation methodology. The study is relevant due to the fact that special attention should be paid to securing cargo during transportation. In this regard, the improvement of securing and calculation methods is one of the security areas in the transportation.

The cargo safety in the transportation largely depends on the correct cargo securing. The improperly secured cargo can shift, tip during transportation, which can lead to damage to the cargo and/or vehicle, road accidents.

The materials of this article are of practical value and can be used in the educational process at the technical university and at the road transport enterprises, logistics centers, dispatching points.

Key words: cargo, vehicle, vehicle body, load, cargo securing device, friction coefficient, stability.

I. INTRODUCTION

The simplest, fastest and most popular form of securing cargo is to load the vehicle, close the body and transport the cargo safely without additional efforts. The carriers have reasons for this. According to the European Standard DIN EN 12642 "Code XL" (2007), the vehicle body sides are subject to strict requirements in terms of strength and rigidity. Thus, the vehicle body front side shall provide without deformation the load perception, which is 50% of the vehicle carrying capacity, but not more than 50 kN, the tailgate - 30%, but not more than 31 kN, and the side walls - 40% [1]. The practice of cargo transportation shows that the presence of strong body sides is not enough to ensure the cargo safety. According to foreign statistics, up to 25% of road accidents involving trucks occur due to the improperly secured or incorrectly placed cargo [2]. Unfortunately, some road traffic participants do not pay sufficient attention to this technological operation, believing that the body structure of modern vehicles provide sufficient reliability against shift, as well as cargo safety. At present, there are no uniform rules for placing and securing cargo in Russia. Their presence will make it possible to establish uniform requirements aimed at reducing the risks of loss, damage to cargo, as well as the risks of dangerous incidents and accidents, thereby increasing road safety.

Securing cargo shall ensure its immobility relative to the vehicle in different situations: when driving on an uneven road, when slowing down and accelerating, on a road with a large lateral or longitudinal slope, in case of traffic accident. However, an excessively strong cargo securing leads to an increase in vehicle downtime for loading and unloading, transportation costs. Taking into account these circumstances, the world has developed the regulatory legal acts concerning the requirements for securing cargo in road transport. Thus, the EU countries have the standard EN 12195-1:2010 "Cargo securing systems on road vehicles - safety" [3]. In addition to this standard, there is the IMO/ILO/UNECE Practice for Loading Cargo in the Cargo Transport Units [4], the Guide to Good European Loading Practice for Road Transport [5], the International Guidelines for Safe Cargo Securing in Road Transport [6]. In Russia, the securing means are calculated in accordance with the annex of the "Safety rules for transportation of passengers and cargoes by road and by urban land electric transport", approved by the Order of the Ministry of Transport of the Russian Federation No. 7 dated January 15, 2014 [7]. In recent years, the works [8–11] have been published on this topic.

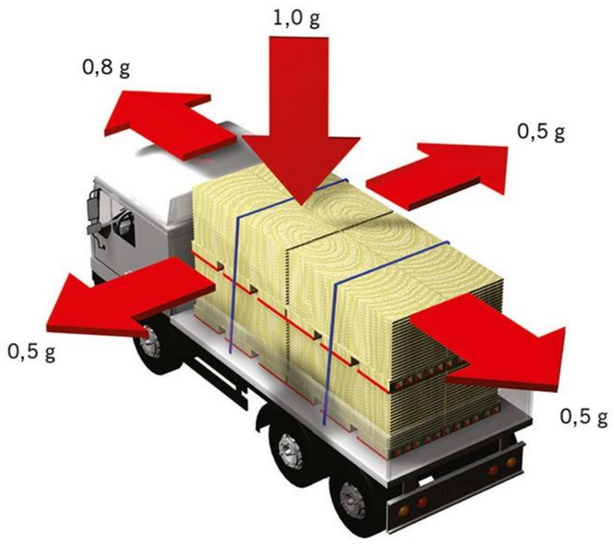
II. METHODS

An analysis of the above regulatory legal acts shows that practical experience and tests carried out have led to a gradual tightening of standards and calculation methods to ensure transport safety. According to the "Safety rules for transportation of passengers and cargoes...", the number of clamping means for securing cargo (belts, cables) is determined by the formula:

$$n > \frac{(c_x - \mu_D \cdot c_z) \cdot m \cdot g}{k \cdot \mu_D \sin\alpha \cdot F_\gamma}, \quad (1)$$

where n – number of cargo clamping means; c_x, c_y, c_z – coefficients of acceleration of inertial forces along the axes x, y, z, respectively; μ_D - kinematic friction coefficient of cargoes and materials; m – weight of cargo, kg; g – free fall acceleration, m/s^2; α – vertical angle between platform and belt, degrees; F_γ - achievable belt tension, H; k – transmission ratio. The belts (cables) are used with one or two ratchet mechanisms, the transmission coefficient (k) is respectively 1.5 or 2.

The values of the maximum calculated load acceleration coefficients in accordance with EN 12195-1:2010 vary within (0.5÷1) g (Fig. 1, Table 1). It should be noted that the maximum calculated inertial forces acting on the load are 10-30% higher than the maximum forces given in DIN EN 12642, for which the vehicle body sides shall be calculated. However, when the load is shifted, some part of the inertial forces will be spent on overcoming the cargo friction force on the platform. But this circumstance does not mean that the cargo does not need to be fixed in the body. When making shift analysis, the friction forces will go into the stability margin.



Picture 1. Maximum calculated accelerations acting on the load

Table 1. The coefficients of the accelerations c_x, c_y, c_z

Direction of action of forces	The coefficients of the accelerations				
	longitudinal c_x		lateral c_y		vertical down c_z
	forward	backward	just a slipping	sliding and tilting	
Longitudinal	0.8	0.5	-	-	1.0
Lateral	-	-	0.5	0.7	1.0

Formula (1) can be used only to calculate the forces leading to the cargo sliding in the longitudinal and transverse directions. It does not allow making the cargo tipping calculation, and it is also impossible to calculate the possibility of vertical movement of the cargo. The "Safety rules for transportation of passengers and cargoes..." does not consider the calculation of the number of clamping means, which prevent tipping. In addition, the rules do not include calculations for different types of fasteners with different cargo location options, the given friction coefficients of materials have a wide scatter, which negatively affects the accuracy of the calculation results.

In practice, one of three cargo methods securing is usually used: blocking, pressing against the platform, securing with guy wires. All methods are aimed at compensating the action of inertial forces by such securing means. When determining the cargo securing methods and choosing the securing means, the following forces acting on the cargo shall be taken into account:

- longitudinal horizontal inertial forces arising during slowdown and acceleration, and from the longitudinal slopes of the road F_x;
- lateral horizontal forces arising from the vehicle movement by roads with a lateral slope and on the corner F_y;
- vertical forces arising from road inequalities F_z;
- friction force between the supporting surface and the cargo F_R;
- cargo gravity G.

The condition of cargo immobility on a horizontal plane will be met, if the following conditions are complied with:

$$F_R \geq F_x;\ F_R \geq F_y.$$

The calculation of securing by the blocking method is reduced to determining the blocking and friction forces with the subsequent comparison of their sum with the corresponding horizontal inertial forces. The blocking force shall correspond to the inequality:

$$F_R > (c_{xy} - \mu_D \cdot c_z) m \cdot g. \quad (2)$$

The value of the kinematic friction coefficient ranges from 0.01 to 0.5. By using a special mat, the kinematic coefficient can be increased to 0.6.

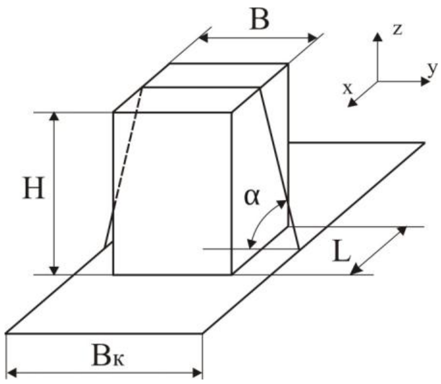
To avoid cargo tipping, check that the following conditions are met:

$$M_{Gy} > M_y;\ M_{Gx} > M_x, \quad (3)$$

where M_{Gx}, M_{Gy} – cargo holding moments against tipping relative to the x and y axes, respectively, M_x, M_y – tipping moments from inertial forces relative to the x and y axes.

The conditions (3) for an unsecured cargo will be met, if the distance from the cargo gravity center to its edge (B) is greater than the gravity center height (h), i.e. $B_x > 0{,}8h$ when tipping forward and $B_y > 0{,}5h$ when tipping to the sides and back. If these conditions are not met, then the use of additional cargo securing devices is mandatory.

Let us consider an example of calculating the clamping means (tie-down belts) as the most common in the transportation practice of bulk general cargo. As the initial calculation data, we will take a cargo in a wooden container with a gross mass of m = 2,100 kg. Cargo package dimensions: height H = 2 m, width B = 2 m, length L = 1.8 m; extension angle α=84°; body floor - wooden (Fig. 2) For the "wood on wood" friction pair, the kinematic friction coefficient is μD = 0.35. When using one clamping device, the transmission coefficient is assumed to be k = 1.5 [5].



Picture 2. Scheme of cargo location on the vehicle platform

The number of securing devices is calculated based on the condition of preventing the cargo sliding and tipping.

When slowing down, a horizontal inertial force affects the cargo and is equal to F_x=0.8·9.81·2.1=16.48 kN.

Friction force of the cargo on the platform F_R=0.35·9.81·2.1=7.21 kN.

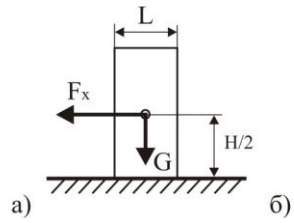
Let us determine the force that needs to be compensated by the clamping device ΔF= F_x- F_R=16.48-7.21=9.27 kN.

In accordance with formula (1), the required belt number is

n>((0.8-0.35·1)·2.1·9.81)/(1.5·0.35·0.97·5)=3.64.

Let it be 4 clamping belts. The number of belts required to keep the cargo from sliding back and sideways is calculated in the same way (Table 2). Since the deceleration coefficient during slowdown c_x is greater than during vehicle acceleration and the coefficient of cargo lateral acceleration c_y, in practice, the required number of belts for given inertia forces may not be calculated.

The cargo tipping may occur forward or backward under the action of a longitudinal force, as well as sideward under the action of transverse inertia forces (Fig. 3).



Picture 3. Diagram of forces applied to the load: a) in calculating the tipping forward; b) when counting on tipping to the side

According to formula (3), the cargo stability condition has the following form:

$$G \cdot \frac{L}{2} > F_x \cdot \frac{H}{2}. \quad (4)$$

Putting the data into inequality (4), we obtain:

2.1·9.81·1.8/2=18.5 < 16.48·2.4/2=19.8 kN·m.

As can be seen from the calculation, the condition for the cargo longitudinal stability is not met, the cargo can tip forward. Due to the fact that at B = H, the lateral inertia force $F_y=c_y \cdot m \cdot g$ is 2 times less than gravity, there is no danger of sideward tipping.

According to the table "Clamping - tipping" [4] with a ratio of the cargo dimensions *H/L* = 1.2, we determine that one belt prevents the forward tipping of the cargo weighting 2 tons. Based on this, the number of belts to prevent forward tipping is determined by the ratio:

n ≥ 2.1/2=1.05.

To prevent tipping, we adopt 2 clamping belts.

Table 2. Results of calculations of the amount of cargo securing means

Parameter	Possible movements of cargo					
	Longitudinal slip forward	Longitudinal slip backwards	Cross slide	Rollover forward	Tilting back	Tilting in the side
Probability of occurrence	yes	yes	yes	yes	no	no
Estimated number of fastening belts	4	2	3	2	-	-

III. RESULTS AND DISCUSSION

According to the calculation results, the largest number of belts determined by different types of impact on the cargo is taken to secure it. In our example, a weight of 2.1 t shall be secured with 4 belts. If the cargo is installed with an emphasis on the front side, the number of belts shall be selected from the condition of preventing the lateral cargo sliding, i.e. 3 belts.

IV. SUMMARY

The results of the works performed allowed making the following main conclusions:

- the main factors affecting the number of necessary clamping fasteners are the cargo securing method, its mass and dimensions, the materials of the contacting surfaces;
- when securing the cargo only with clamping belts and when it is not blocked by other means, it is advisable to calculate the number of belts based on the longitudinal force that occurs when the vehicle is slowing down;
- the use of friction materials (anti-slip mats, etc.) is not widespread enough, which would eliminate or reduce the required number of fasteners;
- it is necessary to develop a unified method to determine the number of fasteners using modern standards, also taking into account the specific nature of road conditions and the organization of road safety, for use in Russia.

V. CONCLUSIONS

Performing calculations using the proposed recommendations allows choosing the optimal number of cargo securing means. At the same time, the safety of the transport process, safety of cargo and efficiency during loading and unloading will be ensured.

VI. ACKNOWLEDGEMENTS

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