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EFFECT ON THE RELATIVE MOVEMENT OF CARGO ON VEHICLE STABILITY

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***Abstract:** The article is a review and provides an overview of the factors influencing the dynamics of the relative movement of the load in the car body. The information written in it will serve as a basis for conducting research related to the dynamics of the relative movement of the load. The purpose of such studies is stated, namely to reduce the number of road accidents that occur due to loss of vehicle stability. Basic concepts related to relative motion and its dynamics in the context of Newton's second law are clarified. The factors that influence the dynamics of relative motion, and hence the stability of a vehicle, are summarized, on the basis of which research on this topic can be planned and conducted. The methods for securing loads according to European practices are indicated in general terms.*

***Keywords:** loads, vehicle stability, dynamics of relative motion, factors, load reinforcement*

INTRODUCTION

The stability of a vehicle is of paramount importance in preventing road traffic accidents. Stability is understood as the combination of a vehicle's properties that ensure its movement along a predetermined direction without lateral skidding or overturning. The loss of stability is often caused by unsecured cargo during transportation. In such cases, the arising inertial, Coriolis, and translational forces lead to a displacement of the cargo during motion, which initiates or accelerates the loss of the vehicle's lateral stability. As a result, the vehicle deviates from its intended trajectory, entering a state of lateral skid or rollover beyond the roadway limits. This process is most often accompanied by material damage, bodily injury, or loss of life. [2]

There are also cases of loss of longitudinal stability, in which—during emergency braking—the unsecured cargo, under the action of inertial forces, slides along the body of the vehicle in its initial direction of motion, passes through the cabin, and causes the death of the driver and passengers.

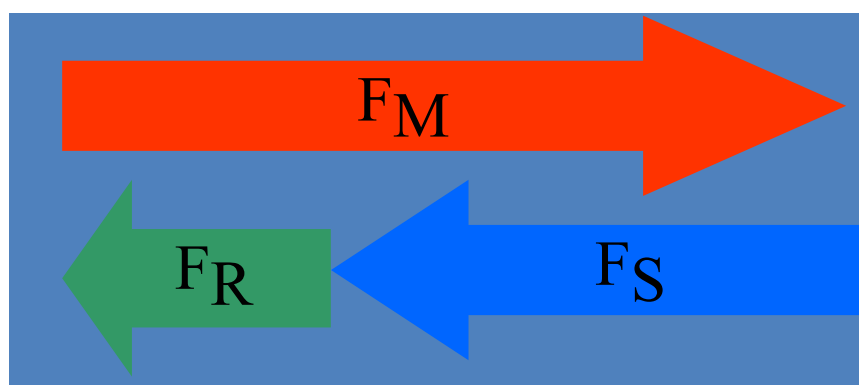
Figure 1 shows real road accidents in the country where the cause was the loss of vehicle stability due to the movement of the cargo relative to the vehicle.



Fig. 1. Road traffic accidents caused by loss of stability

The cargo, including the securing equipment and the loading and unloading devices, must be mounted and fastened in such a way as to prevent sliding, falling, overturning, or noise generation during emergency braking or sudden lateral maneuvers.

A load is considered properly secured when the sum of the frictional force and the securing force is at least equal to the inertial force generated by the mass of the cargo.



$$F_R + F_S > F_M$$

EXPOSITION

The dynamics of relative motion refers to the study of the movement of one object with respect to another (e.g., cargo relative to a vehicle) when both are in motion. In this case, the two objects move at different velocities, and the velocity of one object relative to the other is defined

as the so called relative velocity. Relative velocity is not always a function of deviations in absolute velocity.

By studying the dynamics of relative motion, it is possible to understand the interaction between two or more objects, which allows the motion of each object to be described relative to the others.

The dynamics of the relative motion of the cargo with respect to the vehicle concerns the changes in the position and velocity of the cargo relative to the vehicle during transportation. This phenomenon is particularly important for transport safety, specifically for preventing damage to the cargo and avoiding the loss of vehicle stability, which may result in the vehicle leaving its lane or overturning.

The dynamics of the relative motion of the cargo with respect to the vehicle manifests during acceleration and sudden braking, when driving along a horizontal curve or over an uneven road surface, or in cases of improper securing and placement of the cargo within the vehicle body.

Initially, when studying the relative motion of a point (which precedes the study of the relative motion of a rigid body and subsequently of the cargo), new forces must be introduced. These forces depend on the motion of the moving coordinate system relative to the fixed one, as well as on the relative motion of the point within the moving coordinate system. [3]

If a point is acted upon by forces F_1, F_2, \dots, F_n with a resultant F , its motion relative to the fixed coordinate system is determined by Newton's second law.

$$m \cdot a_a = F, \tag{1}$$

where a_a is the absolute acceleration of the point.

The Coriolis theorem on absolute acceleration states that

$$a_a = a_r + a_e + a_c, \tag{2}$$

where a_r is the relative acceleration of the point;

a_e - the transport acceleration;

$$a_e = a_{O^1} + \vec{\varepsilon}_e \cdot r^1 + \vec{\omega}_e \cdot (\vec{\omega}_e \cdot r^1) \tag{3}$$

a_c - the Coriolis acceleration;

$$a_c = 2\vec{\omega}_e \cdot v_r \tag{4}$$

$\vec{\omega}_e$ - the angular velocity of the moving coordinate system (of the transport motion);

$\vec{\varepsilon}_e$ - the angular acceleration of the moving coordinate system (of the transport motion);

a_{O^1} - acceleration of the moving coordinate system;

r - the distance of the point from the center of the moving coordinate system;

v_r - relative velocity.

By substituting and applying the transformations, the following expression is obtained:

$$m a_r = F - m a_e - m a_c \tag{5}$$

The notations are introduced: $-m a_e = \vec{\Phi}_e$; $-m a_c = \vec{\Phi}_c$, then the following is obtained:

$$m a_r = F + \vec{\Phi}_e + \vec{\Phi}_c \tag{6}$$

The equation is called *fundamental equation of the dynamics of the relative motion of a material point*.

The vectors $\vec{\Phi}_e$ и $\vec{\Phi}_c$ have dimensions of forces and are called respectively transport $\vec{\Phi}_e$ and Coriolis $\vec{\Phi}_c$ inertial force. These additional forces correct Newton's second law when it is applied to arbitrarily moving reference frames.

In conclusion, we can say that the fundamental equation of relative motion dynamics is formulated in the same way as in an absolute system, with the addition of inertial forces – the translational and Coriolis forces – to the applied forces.

From the preliminary studies conducted, the following *factors can be summarized as influencing the dynamics of the relative motion* of the load:

Acceleration a [m/s²] and jerk j [m/s²] during the non-uniform motion of the vehicle. According to the law of inertia, when the vehicle's speed changes, the load tends to maintain its state according to its initial velocity, which could lead to displacement or swinging of the load relative to the vehicle.

- Motion of the vehicle along horizontal or vertical curves – in this case inertial forces occur - $F_{ц.б.} = \frac{m \cdot v^2}{R}$, which tend to move the load toward the outer side of the curve or in the direction of the road's incline. This could be prevented by securing the load.

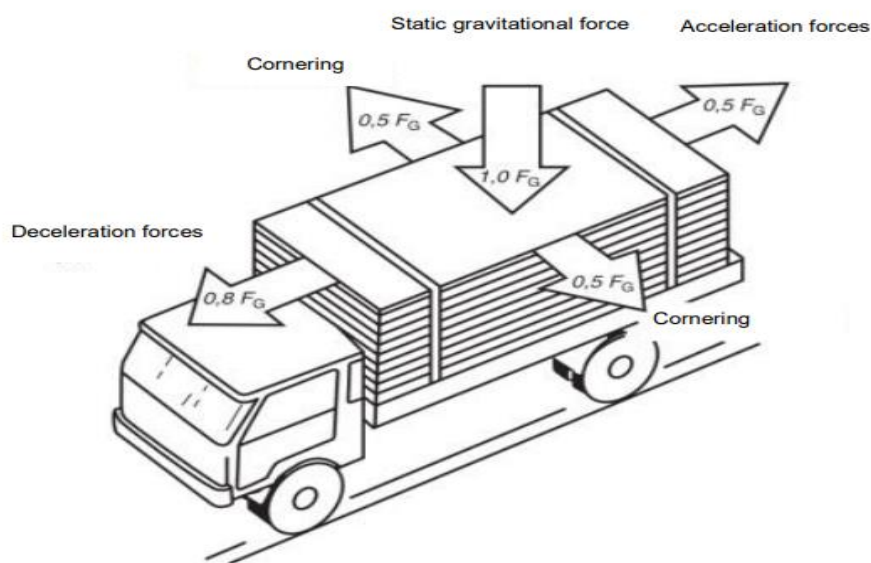


Fig. 3. Forces acting during the transportation of a load by a vehicle

- Mass of the load and the position of the center of gravity of the total load relative to the area and configuration of the vehicle body – there are methods for its precise calculation.

$$S_{res} = \frac{M_1 \times S_1 + M_2 \times S_2 + M_3 \times S_3 + M_4 \times S_4}{M_1 + M_2 + M_3 + M_4} (7)$$

- Coefficient of friction between the load and the vehicle floor – For the accurate determination of the coefficient of friction between different types of loads and the loading surface under various conditions, as well as between the surfaces of loads stacked on top of each other, specialized studies are required.

- Mechanical properties of the load – hardness, shape, and physical state. These properties determine the degree of movement of the load relative to the vehicle under different road conditions.

- Proper distribution of the load along the length and width of the vehicle body – According to transport law, this is the responsibility of both the vehicle driver and the contracting company. Figure 3 shows an example diagram of the correct distribution of the load along the longitudinal axis of the vehicle. [4]

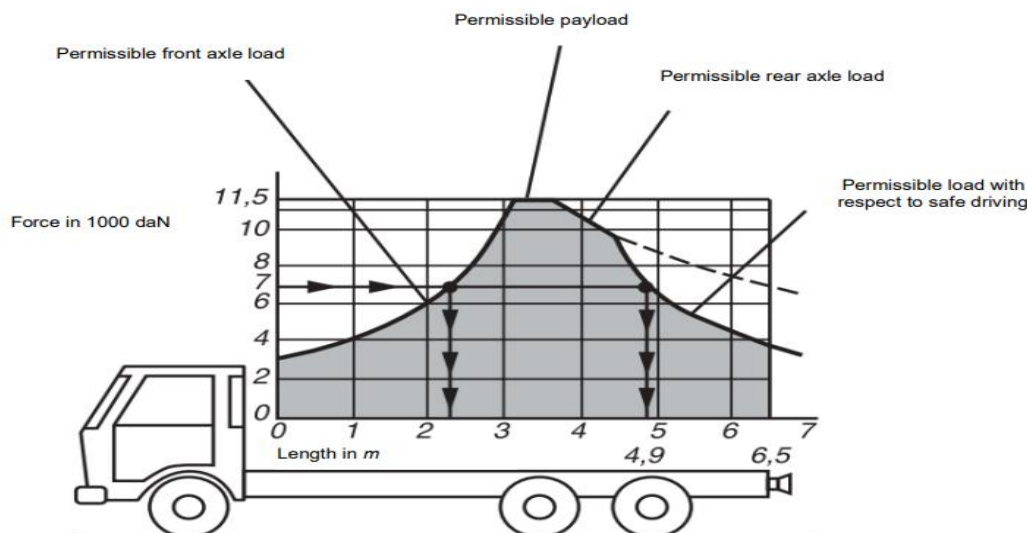


Fig. 3. Diagram of correct load distribution

- Oscillations and swaying of a stationary secured load – these affect the stability and balance of the vehicle.

To control, limit or reduce the relative movement of the load, various *methods and means* are applied to secure it to the vehicle body.

A load is considered reliably secured if its fastening is carried out in such a way that neither road safety, according to traffic law and its subordinate regulations, nor occupational safety is endangered.

According to good European practices, securing the load should involve specific actions aimed at limiting certain types of movements:

- Securing the load using straps and chains;
- Fastening the load with additional corner protectors and anti-slip mats;
- Blocking/locking;
- Using the vehicle structure – walls and cavities;
- Combined load securing methods, etc.

The correct and rational method for determining and recommending permissible load movements should ultimately be based on numerical criteria:

- Allowable sliding/tilting in the longitudinal and transverse directions relative to the geometry of the load and its center of gravity;
- Allowable tilt angle concerning the dynamic load on the securing devices;
- Overall dynamic overload of the securing devices' capacity.

Accounting for load movement and elastic deformation of securing devices requires approaches to calculations that differ from conventional methods, since the input variables for simple equilibrium methods are initially unknown. They are determined only through a relatively long calculation process.

CONCLUSIONS

The loss of cargo stability, followed by a disruption of vehicle stability, is a precondition for a road traffic accident, which can lead to significant material damage, injuries, and fatalities. This necessitates a thorough investigation of the dynamics of the cargo's relative movement within the vehicle body. Based on the results of such a study, a methodology could be proposed to determine the correct and rational way to calculate the permissible movements of the cargo, thereby guiding its effective securing.

At present, when preparing automotive technical expertise, there is no methodology for calculating and determining the causes of traffic accidents resulting from cargo displacement. In this regard, the results of such a study could help in developing a methodology for the technical expert analysis of traffic accidents caused by the loss of cargo stability, which could assist automotive experts in pre-trial and judicial proceedings.

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