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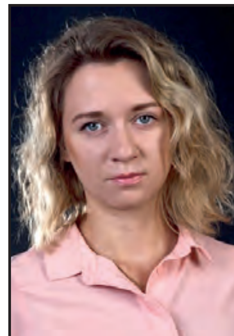
Conditions Leading to Overturning of Empty Containers under the Influence of Wind Load



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ABSTRACT

The article reveals the problems of traffic safety violations resulting from the overturning of empty containers on wind-dependent sections of railways.

The paper refers to examples of several traffic accidents caused by detachment of containers of various types from specialized flat wagons under the influence of a squally wind of various speed. The increase in the number of such traffic accidents urges development of a procedure for safe transit of freight trains, transporting empty containers, if a dangerous weather event may be forecasted along their route.

The objective of this study is to develop an engineering method for determining the conditions leading to overturning of empty containers from specialized railway wagons under the wind load.

Based on the methods of theoretical mechanics, using the moment of force equation as applied to the container relative to the axis of its rotation, the authors found the conditions that cause container overturning under the influence of wind load.

An expression was obtained that allows one to determine the minimum wind speed, which leads to the overturning of an empty container. The article presents the calculation of wind speed leading to the overturning of empty containers of various types for straight and curved sections of the railway track, considering the maximum superelevation (cant) of the outer rail. The obtained results are confirmed by the mathematical modelling of stability of fastening of empty containers by LLC Hexa requested by PJSC Transcontainer.

Based on the cartographic information, the main wind-dependent regions of the Russian Federation were identified where transport accidents caused by overturning of empty containers might occur.

The results of the study can contribute to development of universal technical solutions for different world regions to ensure stability of an empty container when exposed to wind loads.

Keywords: *railway transport, container transportation, rolling stock, wind load, traffic safety violations, traffic accidents.*

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For the original Russian text of the article please see p. 50.

Background. Railway transport is in constant interaction with the environment, working around the clock in the open air, therefore, its clear and uninterrupted operation largely depends on climatic conditions.

Many weather phenomena, individually or in combination with others, lead not only to emergency situations during train movement, but can also temporarily paralyze operation of stations, junctions, and even entire railway directions [1].

These phenomena include weather meteorological phenomena, manifested in the form of a strong wind, a flurry, or a hurricane, which can lead to violations of safety of train traffic [1; 2].

Accidents at world railways show real danger of those risks.

Hence, on the wind-dependent sections of railways of the Russian Federation and CIS countries, there have been several cases of traffic safety violations resulting from overturning of empty containers.

On April 22, 2014, 11 containers with cargo weighing 20 tons were blown away by a squalling wind from a freight container train in the Yamal-Nenets Autonomous District. The wind speed reached 20 meters per second [3].

On December 29, 2015, at 5.30 a.m., with a strong gusty wind of more than 25 meters per second on Vishnevka–Anar section of Karaganda area of the JSC National Company Kazakhstan Temir Zholy, an empty container was overturned from a freight container train [4]. As a result of the emergency, 12 passenger trains were delayed.

On August 13, 2016, at the 8046th kilometer of Domican–Arkhara section of Zabaikalskaya railway, seven empty containers fell from a freight train [5]. The containers fell on an even track and blocked traffic to an oncoming freight train. Train traffic was blocked in both directions. The accident occurred due to a sharp deterioration in weather conditions: empty containers in the rear of the train were blown away by a gale.

Similar situations at railways, referring to container and other trains, occur in Europe and the USA.

On January 3, 2018, in Switzerland a train was derailed by a hurricane wind of a speed of more than 50 m/s. To prevent negative impact of natural disaster the Swiss Federal Railways announced cancellation of transportation on the popular tourist route Jungfraujoch [6].

On March 13, 2019 in the US state of New Mexico, near the settlement of Logan, 26 freight train wagons derailed. The situation was unusual as the wagons fell from the bridge under the influence of a strong wind [7].

Several studies [8–10] included experiments that made it possible to determine local aerodynamic load on rolling stock caused by lateral and headwind. It is worth noting that these studies were aimed at studying stability of traction high-speed rolling stock, while intermodal container transportation did not draw due attention.

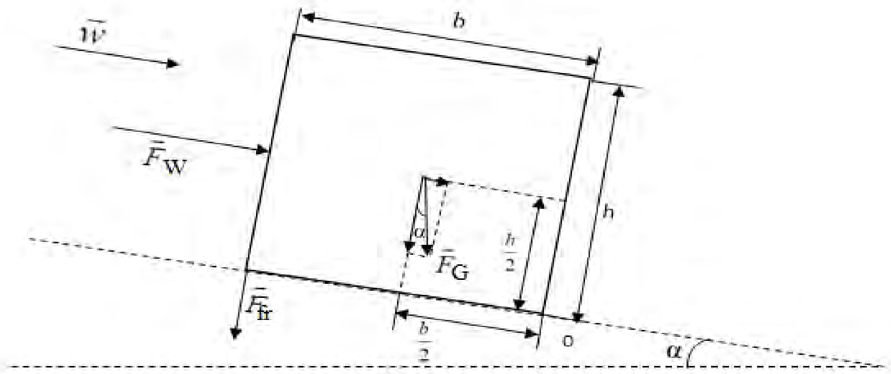
The decree of JSC Russian Railways [2] approved a few measures to reduce the risk of traffic accidents when empty containers are transported on specialized railway wagons under conditions when strong wind, squall or hurricane are forecasted along their route. They are limited to organizational adjustment of the transportation process.

The *objective* of the present study is associated with the necessity to develop an engineering methodology for assessing the characteristics of wind load, leading to the overturning of empty containers in freight trains. The *methods* of theoretical mechanics, comprising moment of force equations.

Results.

Currently, in the field of intermodal transportation, there are uniform requirements for transported containers, their overall dimensions, weight and fastening devices. These requirements are regulated by ISO standards [11, p. 6] and. In Russia, by State standard (GOST) [12, p. 5; 9, p. 4]. In case of transportation by rail, the container is secured to the railway flat wagon with four lower corner fittings using universal cones. Such fastening should prevent sliding and overturning under the action of longitudinal and transverse forces, however, under the influence of additional wind load, this fastening does not justify itself.

Let us find the conditions of the container overturning caused by influence of the wind load based on the equation of the moments of force applied to the container relative to the axis of its rotation when the freight train is moving on the curved section of the railway track (see Pic. 1). The technical operation rules in Russia establish the maximum superelevation of the outer rail on the curved section of the railway track at 150 mm [14, Table 2, 3].



Pic. 1. Scheme of action of forces in the middle section of the container.

The main distributed wind load $\vec{w}$ (Pa) is replaced by the concentrated force of the wind pressure applied to the geometric center of the leeward surface of the container and acting normally to it. We take into account the gravity of the container $\vec{F}_G$, as well as the friction force of the surface of the container along the fittings F_{fr}, acting along the friction surface and arising from the force of wind pressure on the container and from the normal component of the gravity of the container to the friction surface.

Then the equation of the moments of forces applied to the container, relative to the axis of its rotation, will have the following form:

$$\sum_i M_i \geq 0, \quad (1)$$

where $M_i = F_i \cdot l_i$ is product of the force modulus $\vec{F}_i$ and of the arm force;

l_i is the shortest distance from the line of action of the force to the axis of rotation of the container.

The moment of force is considered positive if it rotates the container clockwise, otherwise the moment of force is considered negative.

The forces acting on the container, taking into account the assumptions made, can be written as follows:

• wind pressure force applied to the geometric center of the leeward surface of the container and acting normally to it:

$$\vec{F}_W = \vec{w} \cdot S, H, \quad (2)$$

where $S = L \cdot h$ is area of the leeward surface of the container, m^2 (here *L, h* are length and height of the container, respectively).

• gravity force of the container will act in the center of masses

$$\vec{F}_G = m \cdot \vec{g}, H, \quad (3)$$

where *m* is weight of an empty container.

• friction force of the container on the fittings $\vec{F}_{fr}$, acting along the friction surface

$$F_{fr} = k_{fr} \cdot \left(F_W + F_G \sin\alpha\right), H, \quad (4)$$

where k_{fr} is coefficient of static friction.

Pic. 1 above is a diagram of the middle section of the container, showing the main forces acting on the container when passing a curved track section.

In the middle section the following moments of forces act on the container relative to the axis of rotation:

$$M_1 = F_W \cdot \frac{h}{2}; \quad (5)$$

$$M_2 = -F_G \cos\alpha \cdot \frac{b}{2} + F_G \sin\alpha \cdot \frac{h}{2}; \quad (6)$$

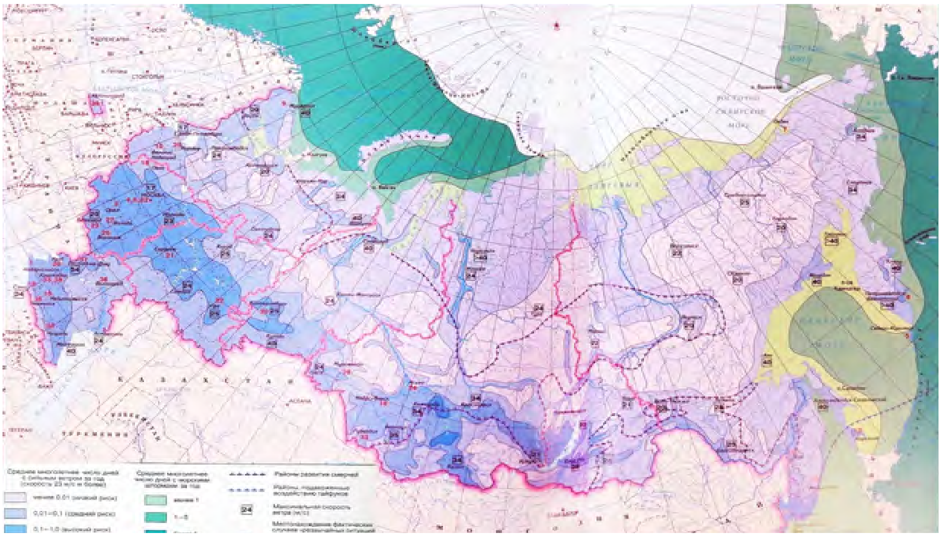
$$M_3 = -F_{fr} \cdot b = -k_{fr}\left(F_W + F_G \sin\alpha\right) \cdot b. \quad (7)$$

From equation (1), taking into account equations (2–7), we obtain the equation for the main wind load, leading to overturning of the container:

$$w \geq \frac{m \cdot g \cdot \left[b\cos\alpha - \left(h - k_{fr} b\right)\sin\alpha\right]}{h \cdot L \cdot \left(h - 2k_{fr} b\right)}, \ Pa. \quad (9)$$

In accordance with [15] the normative value of the main wind load *w* is defined as the sum of the middle w_m and pulse w_p components:

$$W = w_m + w_p. \quad (10)$$



Pic. 2. Risk of strong winds.

In turn, the normative value of the middle component of the main wind load w_m depending on the equivalent height of the container z_e above the ground is determined by the formula [15, p. 18]:

$$w_m = w_0 k(z_e) c, \qquad (11)$$

where $w_0 = 0{,}43V^2$ is normative value of wind pressure;

$k(z_e)$ is coefficient, taking into account the change in wind pressure for equivalent height z_e;

c is aerodynamic coefficient;

V is wind speed, m/s, at the level of 10 m above the surface of the ground.

Then the normative value of pulse component of the main wind load w_p at the equivalent height of the container z_e is determined by the following formula [15, p. 20]:

$$w_p = w_m \cdot \zeta(z_e) \cdot \nu, \qquad (12)$$

where $\zeta(z_h)$ is coefficient of pulsation of wind pressure;

Table 1

Calculation results

Container type	Curved section of railway track			Straight section of railway track		
	Wind load, w, (Pa)	Wind speed V, (m/s)	Classification of winds, [2]	Wind load, w, (Pa)	Wind speed V, (m/s)	Classification of winds, [2]
Three-ton container, UK-3	617,48	24,96	Strong wind, windsquall	724,78	27,04	Strong wind, squall wind
40-foot high container (HighCube), 40' HC	1057,39	32,67	Hurricane	1165	34,29	Hurricane
40-foot standard container (Dry Van) 40' DV	1319,2	36,49	Hurricane	1435,5	38,06	Hurricane
20-foot standard container, (Dry Cube) 20' DC	1466,85	38,48	Hurricane	1596,16	40,13	Hurricane
Five-ton container, UK-5	2444,6	49,67	Hurricane	2620,39	51,42	Hurricane

N is coefficient of spatial correlation of pulsation of wind pressure.

Taking into account equations (10–12), equation (9) can be represented in the following form with respect to *V* (m/s) which is wind speed at the level of 10 m above the surface of the ground:

$$V \geq \sqrt{\frac{m \cdot g \cdot \left[b\cos\alpha - \left(h - 2k_{fr}b\right)\sin\alpha\right]}{0{,}43 \cdot k\left(z_e\right) \cdot c \cdot h \cdot l \cdot \left[1 + \zeta\left(z_e\right)\nu\right] \cdot \left(h - 2k_{fr}b\right)}}. \quad (13)$$

We will calculate the wind speed leading to the overturning of empty containers of various types, both for straight sections of the track and for curved sections of the track of railways, taking into account the maximum superelevation of the outer rail of 150 mm.

Region A as the most dangerous was chosen as the geographical area of the transport accident, its features assume «open coasts of seas, lakes and reservoirs, in rural areas, including those with buildings less than 10 m high, deserts, steppes, forest-steppes, tundra» [15, annex E].

The Pic. 2 shows the map of risks of strong winds in the territory of the Russian Federation [16, p. 152].

The results of calculating the wind speed leading to the overturning of empty containers of various types are presented in Table 1.

The results obtained are confirmed by the mathematical modelling of stability of fastening of empty containers, carried out by LLC Hexa on the demand of PJSC Transcontainer [17].

An analysis of wind speed and the risk of its occurrence shows that the highest frequency of strong winds is observed in the coastal regions of the North and the Far East, and in the steppes in the continental part of the country. In the North of the country, wind speed varies between 28–35 m/s, in the Far East its range is 31–38 m/s, in the steppes of the North Caucasus if is of 28–31 m/s.

These areas are most dangerous as for overturning of empty containers transported by freight trains, especially on curved sections of the railway track. And UK-3 three-ton empty container is the most vulnerable to the impact of wind load among all types of containers.

The significance of conclusions of the research grows as the total transit capacity of Russian container terminals will increase by 2020 and will amount to 11–12 million TEU [18, p. 53] and as there is also a tendency to increase container traffic along the transcontinental EU–China freight corridor, while a significant share of containers sent along this route is empty, and statistics do not take this into account [19].

Conclusion

Since many Russian regions have predetermined characteristics of wind load that can lead to overturning of empty containers in freight trains it is possible to draw a general conclusion. Organizational measures solely do not solve the problem of neutralizing risks of overturning of empty containers. It is necessary to develop technical solutions to ensure stability of the empty container when exposed to wind load, one of those solutions may be developed through a change in the design of the fitting stop.

Since intermodal container transportation is widely used almost worldwide, the methods of calculating wind load applied to different types of empty containers that are suggested in the article, can be adapted to features of railway track in different countries of Europe, North America, Middle East, Northern Africa, Australia, China, Korea, and other countries.

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