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## Method for determining non-uniform loading of gondola cars with bulk cargo

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**Abstract.** Methods of loading gondola cars with bulk cargo are considered and possible types of non-uniform cargo distribution in the car bodies are established.

The most common methods of levelling bulk cargo in gondola cars in the Ukrainian railway network are determined. Designs of equipment for mechanization of levelling bulk cargo in gondola cars are presented, their advantages and disadvantages are considered. Based on the given analysis, it is established that the most efficient way to ensure compliance with the current regulations on the placement of cargo in cars is the timely detection of non-compliance with these requirements at the stage of loading.

The analysis of existing methods for determining the non-uniformity of cargo distribution in the car bodies was conducted. Based on this analysis, a new method for determining the non-uniform distribution of bulk cargo in the car bodies is proposed, which can be used to pre-estimate the compliance of the actual placement of bulk cargo in the car body with the requirements of current regulatory documents immediately after loading and take prompt measures to eliminate the identified inconsistencies.

### 1. Introduction

The volume of shipment in 2019 totaled to 312.9 million tons [1]. Among this, the share of railway transportation is more than 31.3%. In turn, bulk cargo, which is mainly transported in gondola cars, is about 65% of the total volume of railway freight transportation. One of the main indicators of the efficiency of car fleet operation is the rollover of cars, which depends, in particular, on the duration of cargo handling operations. The duration of cargo handling operations obviously depends on the number and technical condition of the means of mechanization of cargo handling points of railway stations and industrial enterprises.

The purpose of the transport industry is providing safe and high-quality railway transportation services to corporative entities and individuals [2]. Assuring the safety of transportation is also relevant when bulk cargo transported in gondola cars.

This is primarily due to the risk of rollover of gondola cars during traveling due to non-uniform distribution of bulk cargo inside the car body (Figure 1). Therefore, the location of cargo inside the car bodies should be regulated, for example [3, 4].

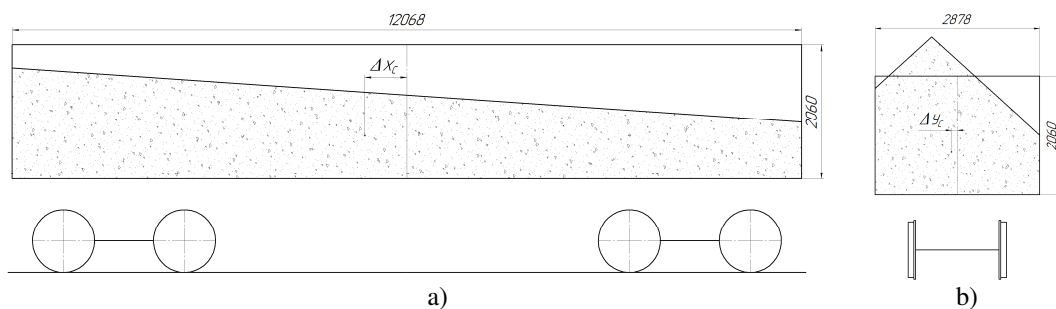
According to the data of Ukrzaliznytsya, about 2/3 of violations of the requirements listed in [3, 4] relate specifically to the non-uniform distribution of bulk cargo in gondola cars. If commodities are loaded in the gondola car non-uniformly, the center of mass of the "car-load" system becomes displaced relative to the geometric center of the car body along the transverse and/or longitudinal axis



of the car (figure 2).



**Figure 1.** Consequences of rollover of a gondola car with bulk cargo.



**Figure 2.** Examples of non-uniform distribution of a bulk cargo in the back of a gondola car:  
a) longitudinally b) transversely.

## 2. Analysis of methods of loading bulk cargo

Non-uniform arrangement of bulk cargo in the body of the gondola car occurs actually during loading of the commodity. The following methods of loading gondola cars with bulk cargo are most commonly used at the Ukrainian railway.

Method 1. Gondola cars move slowly under the loading device, from which the commodity is continuously poured (Figure 3). Often, the cargo surface is compacted immediately after loading, using a passive compactor - a roller (Figure 4). Since the loading device is located above the longitudinal axis of the gondola car, under certain conditions (for example, if the car stops under the loading device), only longitudinal non-uniformity of loading the gondola car body with cargo is possible (Figure 2a).



**Figure 3.** Loading of gondola cars with bulk cargo using a continuous loading device.



**Figure 4.** Compaction of the bulk cargo surface in the gondola car body.

Continuous loading devices are used in enterprises with large volumes of loading of similar loads, such as coal mines, mining and processing plants, etc.

Method 2. Gondola cars are loaded using intermittent loading devices, such as excavators, clamshell cranes, front loaders, etc. In such devices, buckets or clamshell grabs are used as working elements (Figure 5).



**Figure 5.** Loading of gondola cars with bulk cargo using loading devices of intermittent operation.

This method is used in enterprises with medium or small loading volumes and/or with a wide range of commodities loaded as bulk cargo. Since the loading device operator's view of the internal part of the gondola car body is limited or impossible, a transverse non-uniformity of loading of the gondola car body with cargo may occur (Figure 2B).

### 3. Technical means for leveling bulk cargo

In the Ukrainian railway network, the surface of bulk cargo in the bodies of gondola cars is levelled both using a mechanized method with excavators or clamshell excavators, and a non-mechanized method with manual leveling of the surface of bulk cargo (Figure 6).

The leveler attachment for bulk cargo in gondola cars designed in the Ukrainian State University of Railway Transport is also known (Figure 7) [5, 6].

A specific feature of this device is the use of working tools in the form of rotors with attached blades. After the crane lowers the device on the top of a gondola car, power supply of rotor drives is switched on. With further lowering, the rotors immerse in the cargo and begin to level the part of the cargo located under the working tools. To level the rest of the cargo, the device is moved to the desired location.

The leveler was produced at the State Enterprise "Vinnytsiatransprilad" [7]. Its operation has shown high performance on cargo with high and medium flowability, such as crushed stone. For such cargo as chalk or iron ore concentrate, the efficiency of the rotary tools was insufficient.

Therefore, the specialists of the Ukrainian State University of Railway Transport proposed a new design of an attachment for leveling the surface of bulk cargo in gondola cars featuring the use of screw working tools (Figure 8) [8].

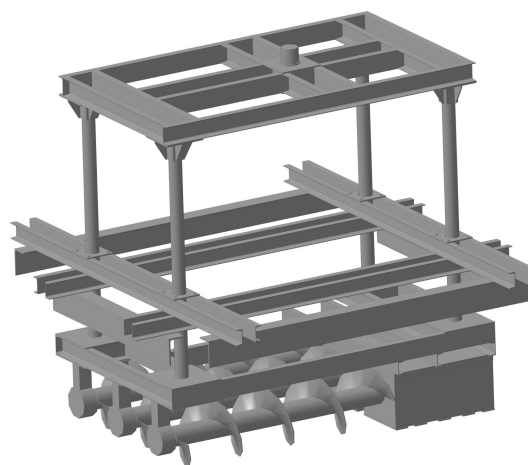




**Figure 6.** Common methods of levelling the bulk load:  
a - manually; b – with a clamshell excavator.



**Figure 7.** Leveler attachment for bulk cargo in gondola cars.



**Figure 8.** Screw leveler attachment for bulk cargo in gondola cars.

#### 4. Method for determining the non-uniform placement of bulk cargo in the car bodies

It is generally known that the best way to eliminate the consequences of any emergency is to prevent the occurrence thereof. Regarding the non-uniform loading of gondola cars with bulk cargo, this may be achieved by:

- determination of loads on freight car bogies by means of car scales;
- pre-estimation of the position of the prism vertices of the cargo relative to the longitudinal and transverse axes of the car visually and/or using simple measuring devices, such as measuring tapes.

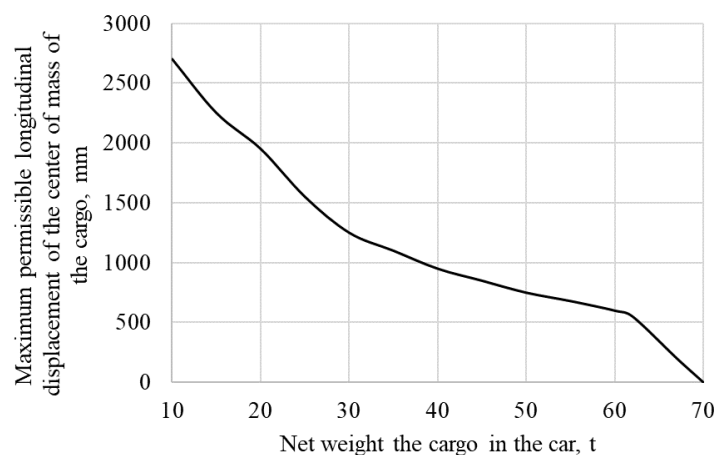
As for the first method, paragraph 4.1.8 of DSTU GOST 22235: 2015 [9] regulates the difference in the loading of car bogies, which can be determined using car scales. The obvious disadvantage of this method is the high cost of use. In addition, performing control weighing of cars and leveling the cargo in the car bodies leads to an increase in downtime of cars during cargo handling operations and, as a result, to a decrease in the efficiency of utilization of the rolling stock.

To implement the second method, the requirements of current regulatory documents can be applied, such as the Rules [3]. Figure 9 shows a graph of dependence of the maximum permissible longitudinal displacement of the center of mass of the cargo (hereinafter - CM) during loading on the weight of the cargo in the back of the car, while Figure 10 shows a graph of dependence of the maximum allowable transverse displacement of CM of the cargo during loading on the weight of cargo in the back of the car and the total height of CM of the loaded car. These graphs are based on the data provided in paragraphs 4.3 and 4.4 of Chapter 1 of the Rules [3].

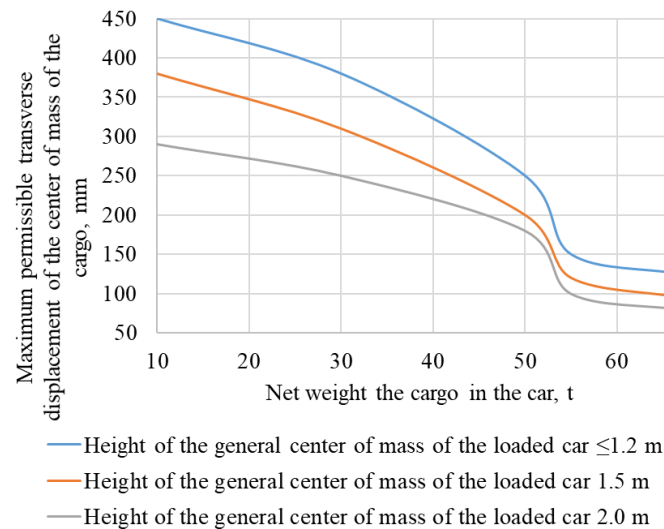
This method is widely used for pre-estimation of the longitudinal displacement of the center of mass of the cargo in the body of a gondola car. However, Figure 10 shows that for a pre-estimation of the transverse displacement of the center of mass of the cargo in the body of the gondola car, the total center of mass of the “gondola-cargo” system should be determined. Performing these estimations for each car will take too much time, which consignors cannot afford. Therefore, the method of pre-estimation of the transverse displacement of the center of mass of the load in the body of a gondola car needs to be improved.

To improve the above method of pre-estimation of the transverse displacement of the center of mass of the load in the body of the gondola car, certain initial data are required which are listed in table 1.

In Ukraine, more than 31% of bulk cargo is transported in gondola cars [10], and for certain categories of cargo, the share of such cars can amount up to almost 100 %. For example, 99.96% of coal, 93.6% of coke, 55.7% of construction materials, and 90.4% of iron and manganese ores are transported in gondola cars. Also, in Ukraine, actually no other cars, except four-axle gondola cars are used. On this basis, the characteristics of a typical gondola car can be set (table 2).



**Figure 9.** Dependence of the maximum permissible longitudinal displacement of the center of mass of the cargo during loading on the weight of the cargo in the car body.



**Figure 10.** Dependence of the maximum permissible transverse displacement of the center of mass of the cargo during loading on the weight of the cargo in the car body and on the total height of the center of mass of the loaded car.

**Table 1.** Initial data for pre-estimation of the transverse displacement of the center of mass of the load in the body of the gondola car

Indicator	Unit	Note
1 Indicators that depend on the specification of the car		
1.1 Internal length of the body	m	
1.2 Internal width of the body	m	
1.3 Internal height of the body	m	
1.4 Tare weight of the car	t	
1.5 Load capacity of the car	t	
1.6 Height of the center of mass of an empty car from the top of the rail	m	paragraph 11.4.1 of the Rules [3]
2 Indicators that depend on the specification of the cargo		
2.1 Density	t/m <sup>3</sup>	
2.2 Natural slope angle	degree	

**Table 2.** Specification of a typical gondola car

Indicator	Value
1 Internal length of the body, m	12.0
2 Internal width of the body, m	2.88
3 Internal height of the body, m	2.06
4 Tare weight of the car, t	22.2
5 Load capacity of the car, t	69.0
6 Height of the center of mass of an empty car from the top of the rail (according to paragraph 11.4.1 of the Rules [3])	1.13

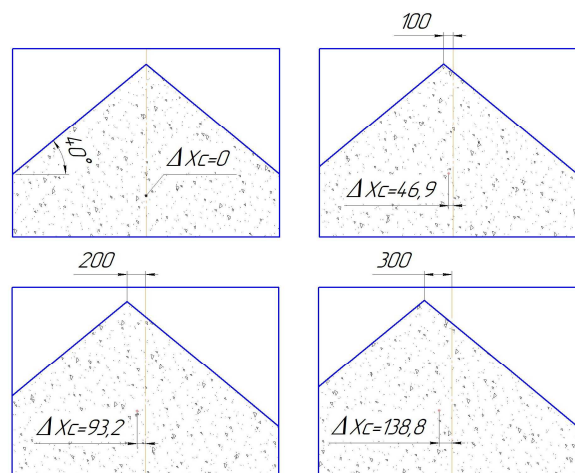
Among the entire range of bulk cargo, three most common commodities were selected: coal, crushed granite stone, and iron ore concentrate, the specification of which are shown in table 3.

It is logical to assume that to increase the efficiency of transport, the carriers will try to maximize the use of the capacity of gondola car, and the dependence of displacement of CM of the load from the displacement of vertices of the prism of cargo in the back of the gondola car can be determined. On

this basis, the weight of the cargo in the gondola car was set (67 t). Figure 11 shows the estimation schemes for determining the transverse displacement of the CM of crushed stone.

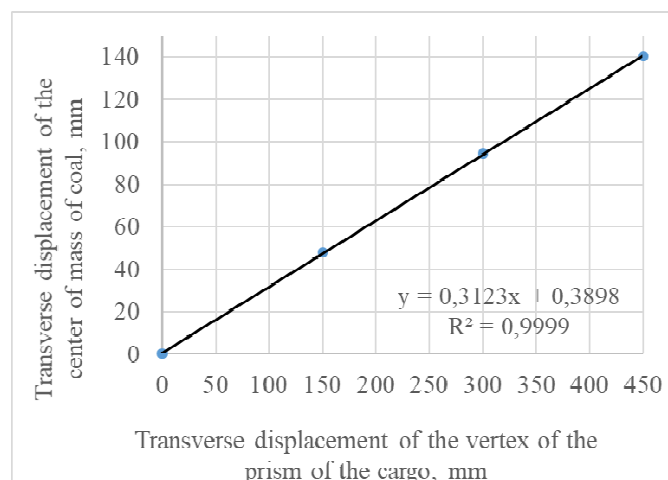
**Table 3.** Specification of bulk cargo

Indicator	Name of cargo		
	coal	crushed granite stone	iron ore concentrate
1 Density, t/m <sup>3</sup>	0.95	1.5	3.1
2 Natural slope angle, degrees	42	40	38



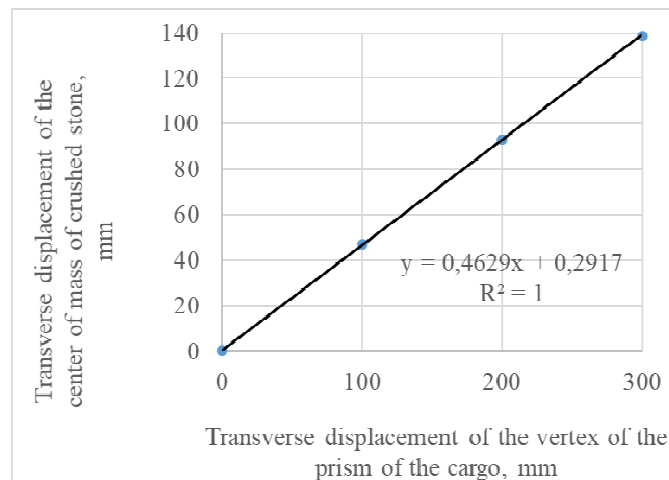
**Figure 11.** Estimation scheme for determining the transverse displacement of the center of mass of crushed stone from the transverse displacement of the vertex of the prism of the cargo.

The results of the estimations were the dependence of the displacement of the cargo CM on the displacement of the vertices of the prism of the cargo (Figures 12-14). In the article [11] it is proved that the longitudinal displacement of the CM of the cargo only slightly affects the stability of the car during movement. Therefore, only the transverse displacement of the CM of the cargo was considered here.

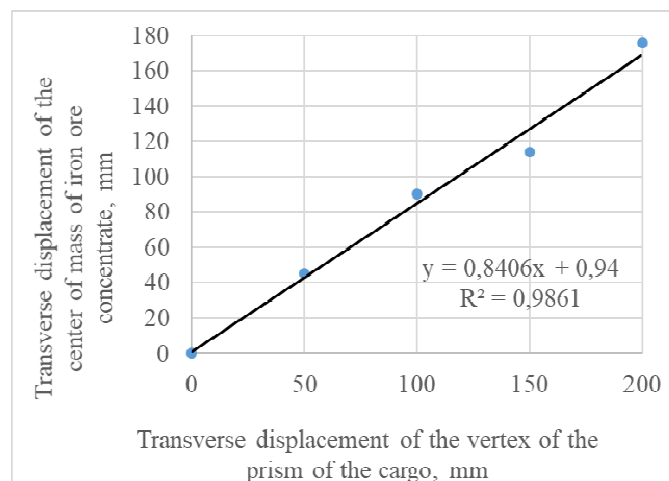


**Figure 12.** Transverse displacement of the center of mass of coal from the transverse displacement of the vertex of the prism of this cargo.





**Figure 13.** Transverse displacement of the center of mass of crushed stone from the transverse displacement of the vertex of the prism of this cargo.



**Figure 14.** Transverse displacement of the center of mass of iron ore concentrate from the transverse displacement of the vertex of the prism of this cargo.

Figures 12-14 show that the regression equations based on the calculated points has the form

$$y = a \cdot x + b, \quad (1)$$

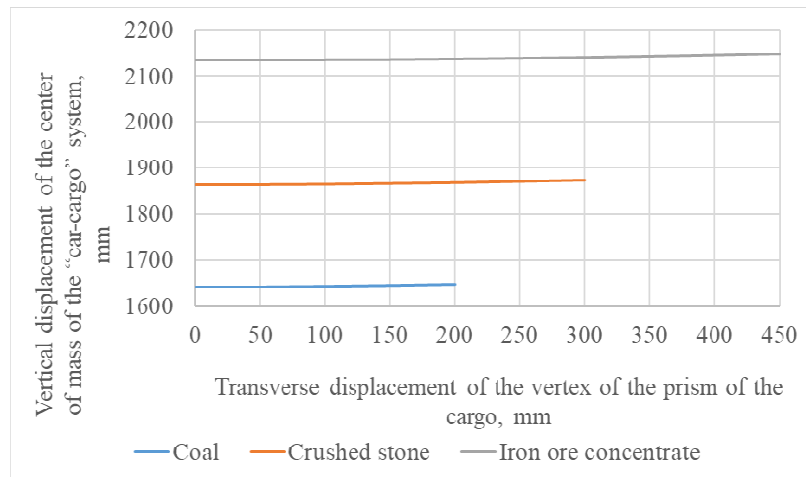
where  $y$  is transverse displacement of the CM of the bulk cargo from the vertical axis of symmetry of the gondola car body;  $a$ ,  $b$  are constant coefficients;  $x$  is transverse displacement of the top of the bulk cargo from the vertical axis of symmetry of the gondola car body.

In this case, the height of the CM of the “car-cargo” system increases insignificantly (Figure 15).

Thus, the procedure for pre-estimation of the transverse non-uniformity of loading a gondola car with bulk cargo is as follows.

- The total height of the CM of the “car-cargo” system is determined. In practice, the following can be assumed: if the cargo density is less than  $1 \text{ t/m}^3$ , the height of the CM of the “car-cargo” system from the top of the rails above 2 m, and if the cargo density is more than  $1 \text{ t/m}^3$ , the height of the CM “car-cargo” system from top of the rail heads level less than 2 m.
- In accordance with paragraph 4.4 of Chapter 1 of the Rules [3], the maximum permissible transverse displacement of the CM of the “car-cargo” system is assigned.
- The transverse displacement of the vertex of the prism of the cargo is measured.
- Using the graphs, examples of which are shown in Figures 12-14, the calculated value of the

transverse displacement of the CM of the “car-load” system is set and compared with the maximum allowable value, which was assigned in paragraph 2.



**Figure 15.** Vertical displacement of the center of mass of the “car-cargo” system from the transverse displacement of the vertex of the prism of the cargo.

## 5. Conclusions

Based on the above, the following conclusions can be drawn:

- methods of loading gondola cars with bulk cargo are considered and possible types of non-uniform placement of cargo in the car bodies are established;
- the existing methods for determining the non-uniformity of cargo placement in the car bodies are considered, their disadvantages and difficulties of application are established;
- a new method for determining the non-uniform placement of bulk cargo in the car bodies is proposed, which allows you to pre-estimate the compliance of the actual location of bulk cargo in the car body with the requirements of the applicable regulatory documents immediately after loading and promptly take measures to eliminate inconsistencies, if any;
- to use the proposed method successfully, dependencies must be available on displacement of CM of the “car-cargo” system on the displacement of vertices of the prism of cargo in the back of the gondola car for the main item of bulk cargo transported in cars.

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