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ANALYTICAL MODELLING CARGOES DISPLACEMENT IN WAGON AND TENSION IN FASTENING

Summary. The article deals with the conclusions of analytical modeling cargoes displacement relative wagon and tension in fastening on exposure to spatial system of forces.

АНАЛИТИЧЕСКОЕ МОДЕЛИРОВАНИЕ СДВИГА ГРУЗА В ВАГОНЕ И НАТЯЖЕНИЙ В КРЕПЛЕНИЯХ

Аннотация. В статье изложены выводы аналитических формул сдвига груза относительно вагона и натяжений в креплениях при воздействии пространственной системы сил.

1. FORMULATION OF A PROBLEM

Up to date there has not been developed a theory of cargo fastening on the open rolling stock under the impact of spatial force systems on the system „wagon-cargo-fastening".The regulations do not include assessment of safety operation on the criterion of cargo shear relative to the wagon because in all availlable regulations there isn't any notion of cargo shear in a wagon, to say nothing of calculating its value. Due to this fact there has not been done any assessment of operation safety of a wagon with asymmetrically allocation cargo both lengthwise and crosswise the wagon as compared with the operation of wagons with symmetrical allocation. It would be reasonable to assess operation safety using the criterion of cargo shear relative to the wagon by constructing summarized dynamic and mathematical models of fastenings of asymetrically allocation cargo both lengthwise and crosswise the wagon as compared to symmetrical allocation. In connection with this let us assume as a basis of a mathematical model that the action of spatial system of forces just as in reality is received by the main (the wagon) and additional constraints (flexible elastic and persistent wooden fastening means). Let us consider the general case when cargo weighing $\overline{G}$, is allocation asymmetrically (or symmetrically) relative to the longitudinal and transversal symmetry axes of the wagon the physical model of which is shown in Fig. 1,a,b.

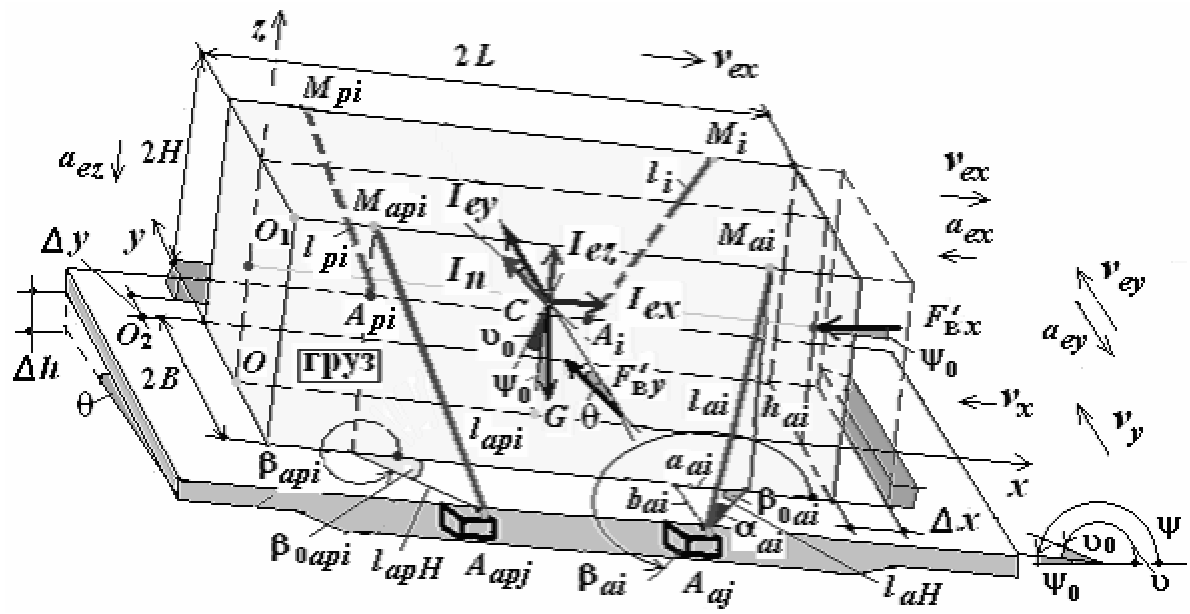


Fig. 1a. Physical modeling allocation cargoes in wagon, running on the curve section of railway descent (side view)
Рис. 1a. Физическая модель размещения груза в вагоне, движущегося по кривому участку пути на спуск (вид сбоку)

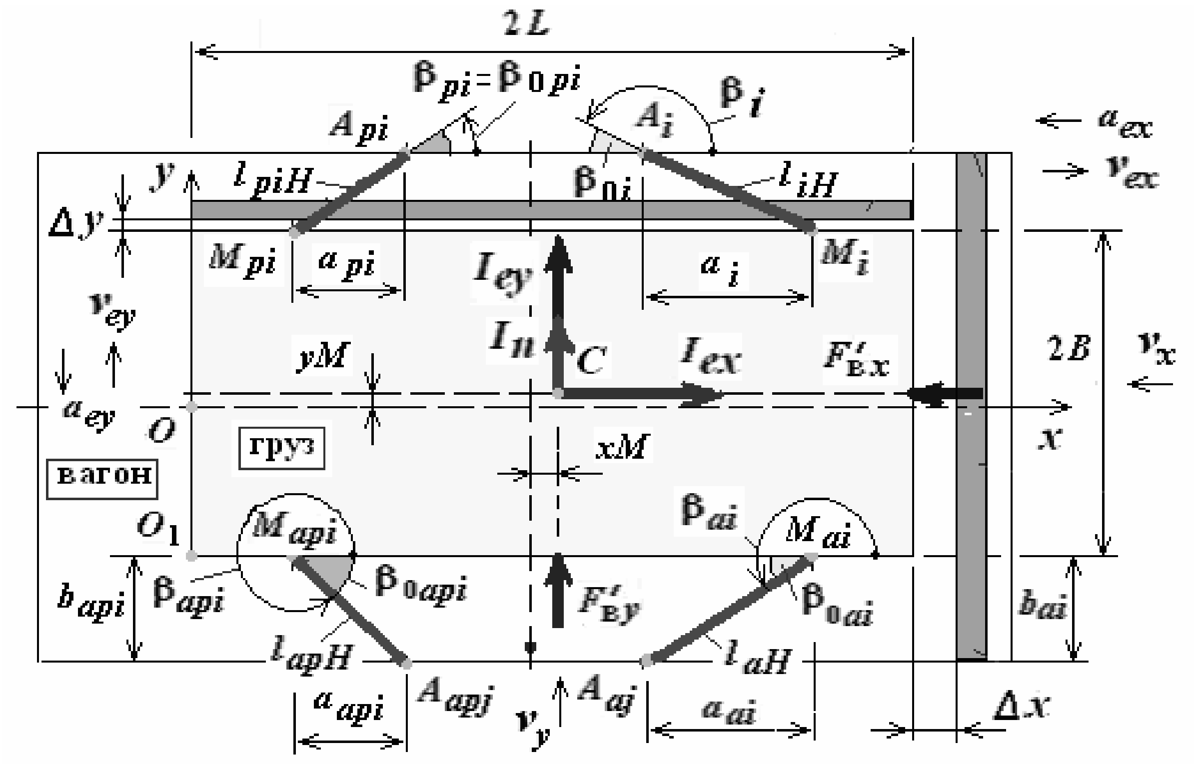


Fig. 1b. Physical modeling allocation cargoes in wagon, running on the curve section of railway descent (top view)
Рис. 1b. Физическая модель размещения груза в вагоне, движущегося по кривому участку пути на спуск (вид сверху)

In Fig. 1 the following symbols are accepted j and i are indexes showing the numbers of rack brackets in wagon and elastic fastening elements ($i=\overline{1,n_p}$ – a number of flexible elastic fastening elements); $2L$, $2B$ и $2H$ – are cargo length, width and height accordingly; a_i и a_{ai} – are the projections of flexible elastic fastening elements of one direction on the longitudinal wagon axis x (a_{pi} и a_{api} –are also of another direction); b_i и b_{ai} – are projections of flexible elastic fastening elements of one direction on the transversal axis of wagon y (b_{pi} и b_{api} – are also of the other direction); h_i, h_{ai}, h_{pi} и h_{api} – are projections of flexible elastic fastening elements on the vertical axis of wagon z; l_i и l_{ai} – is the length of flexible elastic fastening elements of one direction (l_{pi} и l_{api} – are also of the other direction); l_{wi} и l_{wai} – are projections of the length of flexible elastic fastening elements of one direction on the transversal axis of wagon y (l_{wpi} и l_{wapi} – are also of the other direction); α_i и α_{ai} –a re the angles which are formed by the fastening elements with the flat surface of the floor of wagon of one direction (α_{pi} и α_{api} – are also of the other direction); β_i и β_{ai} – are the angles that are formed by the projections of fastening elements (l_{iH}, l_{aiH}, l_{piH}, l_{apiH}) on the plane of the floor of the wagon of one direction with axis x (β_{pi} и β_{api} – are also of the other direction (β_{0i}, β_{0ai}, β_{0pi} и β_{0api} – are the same angles only they are acute); Δh – is superelevation; $2S$ –is the distance between wheel rolling circles of wagon wheelset of gauge 1520 mm ($2S$ = 1580 мм); θ – is the angle characterizing superelevetion; ζ – is the angle taking into account tilting of the frame of the wagon with cargo being displaced on the transversal axis of wagon y by the value $\pm yM$.

1.1. Man-made assumption

Let us assume that rolling stock is moving along a downgrade at the angle ψ_0 both in the regime of release and the regime of service braking at a speed of $\bar{v}$ on a curve with curvature radius ρ of trajectory in the particular point of the curve. The cargo is fastened to the wagon binding devices by the fastening flexible elastic elements at points A_j, A_{aj}, A_{pj} и A_{apj} ,and to its load gripping hinges – at points M_i, M_{ai}, M_{pi} and M_{api} (Fig. 1). Let us assume that the cargo is placed on the floor of the wagon and is kept from shear by flexible elastic and persistent fastening means, the wagon floor being the main constraint and flexible elastic fastening elements and persistent wooden bars (if they are available) the additional constraint. [1, 2]. We assume that external constraints undergo the impact of cargo weight $\bar{G}$, longitudinal ($\bar{I}_{ex}$), lateral ($\bar{I}_{ey}$), vertical ($\bar{I}_{ez}$) transient forces of inertia; forces of aerodynamic resistance $\bar{F}_в$ and axial force of inertia ($\bar{I}_n$), taking into account the motion of rolling stock on a curve. We'll take into consideration the fact that the maximum normative values of transversal transient accelerations $\bar{a}_{ex}^{\max}=\bar{a}_{ex}$ are equal to $a_{ex}=0{,}3g$ –on a tangent, $a_{ex}=(0{,}7-1{,}2)g$ –during service braking, $a_{ex}=(1{,}2-2)g$ – during impacting of wagons in the hump yard, and the vertical transient accelerations $\bar{a}_{ez}^{\max}=\bar{a}_{ez}$, due to aberrations in track maintenance – $a_{ez}=(0{,}46-0{,}66)g$. According to this it is possible to assume $I_{ex}=0{,}3G$ –on the tangent, $I_{ex}=(0{,}7-1{,}2)G$ –during service braking $I_{ex}=(1{,}2-2)G$ –during impacting of wagons in hump yards and $I_{ez}=(0{,}4-0{,}66)G$. Vertical transient force of inertia $\bar{I}_{ez}$ occurs (i. e. $\bar{I}_{ez}\neq 0$) during the movement of the wagon with cargo on the tangent without braking and in the regime of release along a downgrade and in the regimes of braking and impacting wagons

2. METHODS OF SOLUTION

Let us apply the principle of clear constraints and the law of relative transient motion [1-3].

We introduce the notion "shearing" and "retaining" forces [3], acting lengthwise and crosswise the wagon and received by the fastenings of one (longitudinal or and transverse) direction without taking into account friction forces $\overline{F}_\tau$ and elastic fastening forces $\overline{R}_i$, but with account of tension of preliminary twistings of wire fastenings.

Definition 1. „Shearing" force is the sum of all forces causing the shift of cargo relative to the floor of the wagon.

Statement 1."Shearing ' force is a harmful force for cargo threatening traffic safety and hazardous for cargo safekeeping and it is the major force damaging the elements of rolling stock creating potentially the situation of near-accident.

Definition 2. „Retaining" force is the sum of all reactive forces keeping the cargo from shifting relative to the floor of the wagon.

To reactive forces with points of application can be referred: $\overline{R} = F_{\tau x}\overline{i} + F_{\tau y}\overline{j} + N\overline{k}$ − is the reaction of the main constraint (wagon floor) to unknown application point data x_R and y_R, $F_{\tau x} = F_{mp.x}$, $F_{\tau y} = F_{mp.y}$ and N being the projections of reaction of constraint $\overline{R}$ on coordinate axes x, y and z; $\overline{R}_i = R_{ix}\overline{i} + R_{iy}\overline{j} + R_{iz}\overline{k}$ −tension in i-x flexible elastic elements of fastening cargo with given points of application x_i, y_i и z_i, R_{ix}, R_{iy}, R_{iz} −being the projections of constraints $\overline{R}_i$ on coordinate axes x, y and z; $\overline{R0_i}$ −are tensions of preliminary twistings in i-flexible elastic fastening elements where $R0_{ix}$, $R0_{iy}$, $R0_{iz}$ −are projections of tensions $\overline{R0_i}$ on coordinate axes x, y and z; $i = \overline{1, n_p}$ − the number of flexible elastic fastening elements.

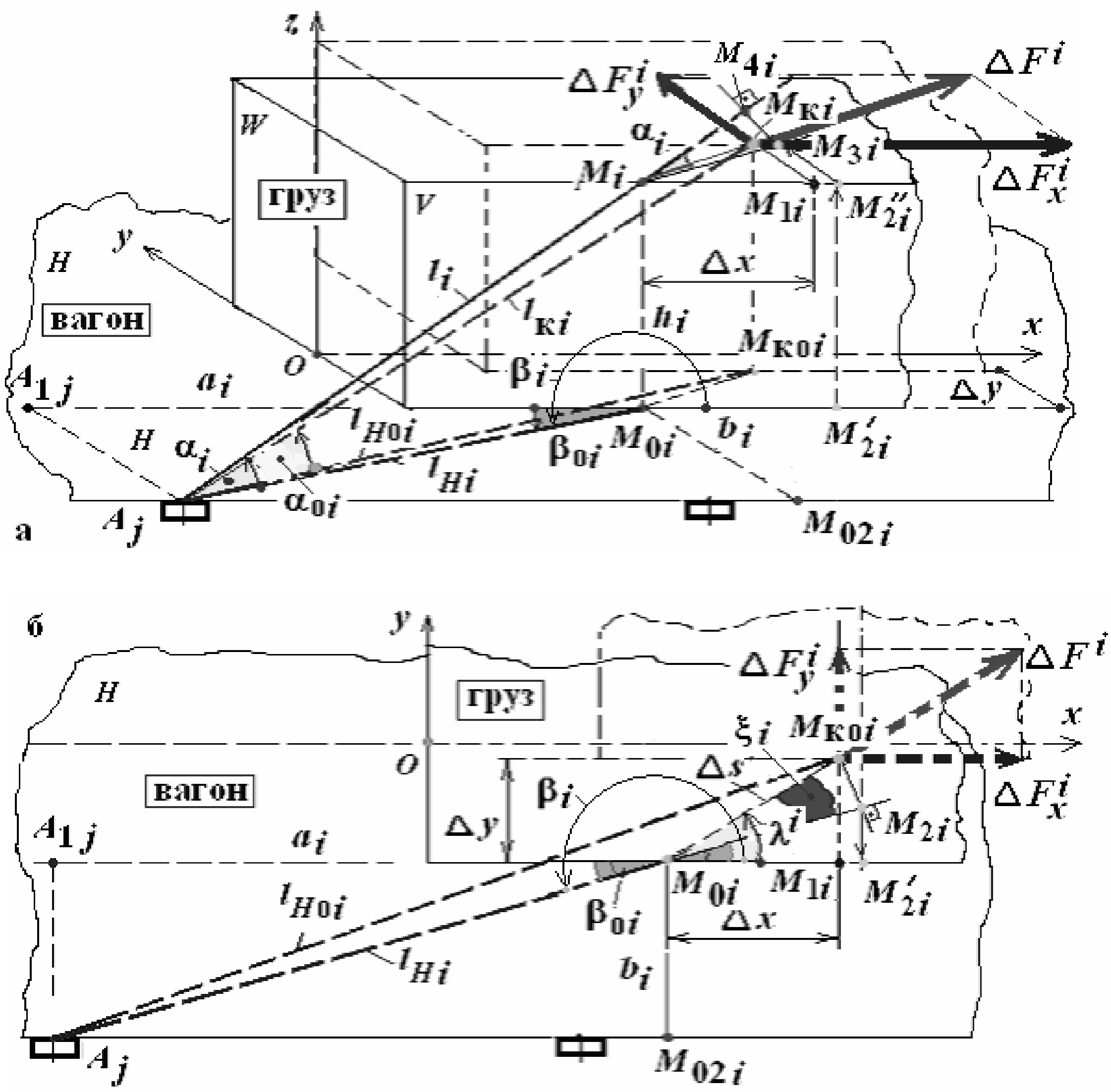
Statement 2."Retaining" force is a beneficial force for cargo ensuring safety of movement, cargo safekeeping and preventing the elements of rolling stock from damage.

3. SOLUTION RESULTS

Let us consider a general case when cargo shear (Δs) occurs relative to the action of the resultant of spatial forces systems $\Delta F^{(i)}$ (Fig.2).

Fig. 2 contains the following symbols: M_i – are points showing mounting hinges and their projections on horizontal and vertical planes; l_i и a_i, b_i, h_i – are lengths of flexible elastic fastening elements and their projections; Δs – cargo shear in relation to the action of the resultant of spatial forces systems $\Delta F^{(i)}$, which is to be found; ξ_i – angle characterising cargo shear in the plane of the wagon floor.

In accordance with the method of identification of deformation at minor displacements let us project a „new" position of cargo fixation point (point M_{ki}) on the „original" or „old" direction $A_i M_i$ of flexible elastic element [1, 2]. After simple mathematical computation we get the dependence of lengthening of flexible elastic fastening elements on cargo shear in the plane of the wagon floor



a

b

Fig. 2. General modelling cargoes displacement: a) – axonometric; b) – top view
Рис. 2. Обобщённая модель сдвига груза: a) – аксонометрия; b) – вид сверху

$$\Delta l_i = \Delta s\left(\frac{a_i}{l_i}\cos\lambda^{(i)} + \frac{b_i}{l_i}\sin\lambda^{(i)}\right) \tag{1}$$

where a_i и b_i – are the projections of the length of fastening wire l_i lengthwise and crosswise the wagon; $\lambda^{(i)}$ – is the angle characterising the direction of spatial forces systems relative to the longitudinal axis of the wagon.

Thus the lengthening in the flexible elastic fastening element under the action of spatial forces system occurs only when there is cargo shear in the plane of wagon floor by the value Δs.

Leaving out interim mathematical computation we find the dependence of cargo shear in the plane of the wagon cargo under the action of the resultant spatial forces systems

$$\Delta s = \frac{\Delta F^{(i)}}{7.854 d_i^2 \sum_{i=1}^{n_p} \frac{n_i}{l_i} B_i \sqrt{\left(C_i \cos\lambda^{(i)}\right)^2 + \left(D_i \sin\lambda^{(i)}\right)^2}} \tag{2}$$

where d_i, n_i и l_i – is the diameter (mm), the number of threads (pcs.) and the length of fastening wire; B_i, C_i и D_i – are nondimensional variables

$$B_i = \left(\frac{a_i}{l_i}\cos\lambda^{(i)} + \frac{b_i}{l_i}\sin\lambda^{(i)}\right);\ C_i = \left(f\frac{h_i}{l_i} + \frac{a_i}{l_i}\right);\ D_i = \left(f\frac{h_i}{l_i} + \frac{b_i}{l_i}\right).$$

Taking into account that h_i – is the projection of the length of fastening wire l_i on vertical axes; f – is friction coefficient between the surfaces of wagon floor and cargo.

In formula 1 let us present the resultant of spatial forces systems $\Delta\overline{F}^{(i)}$ (Fig 1), received by the flexible elastic fastening elements as

$$\Delta\overline{F}^{(i)} = \Delta F_x^{(i)}\bar{i} + \Delta F_y^{(i)}\bar{j}, \tag{3}$$

where the projections of constituent forces on longitudinal and transverse axes and on the direction cosine are presented as

$$\Delta F_x^{(i)} = \sum_{i=1}^{n_p} R_{ix} + f\sum_{i=1}^{n_p} R_{iz}\cos\lambda^{(i)}; \tag{4}$$

$$\Delta F_y^{(i)} = \sum_{i=1}^{n_p} R_{iy} + f\sum_{i=1}^{n_p} R_{iz}\sin\lambda^{(i)};\quad \cos\lambda_0^{(i)} = \frac{\Delta F_x^{(i)}}{\Delta F^{(i)}}, \tag{5}$$

It is known that in expressions (4) and (5) the projections of elastic forces (R_{ix}, R_{iy} и R_{iz}) i-x flexible elastic fastening elementsг are connected by the following correlations

$$R_{ix} = R_i\frac{a_i}{l_i};\ R_{iy} = R_i\frac{b_i}{l_i};\ R_{iz} = R_i\frac{h_i}{l_i} \tag{6}$$

In its turn, in (4) и (5) $\Delta F_x^{(i)}$ and $\Delta F_y^{(i)}$ re presented by the following correlations

$$\Delta F_x^{(i)} = \Delta F_x^{0i} - F_\tau^e\cos\lambda^{(i)};\ \Delta F_y^{(i)} = \Delta F_y^{0i} - F_\tau^e\sin\lambda^{(i)} \tag{7}$$

where $\Delta F_x^{0(i)}$ – is the longitudinal force received by the fastenings of one direction as the difference of „shearing" and „retaining" forces

$$\Delta F_x^{0i} = F_{сд.x} - F_{уд.ix} \tag{8}$$

$\Delta F_y^{0(i)}$ – s the transverse force received by the fastenings of one direction as the difference of shearing and retaining forces

$$\Delta F_y^{0i} = F_{сд.y} - F_{уд.iy} \tag{9}$$

$\lambda^{(i)}$ – the direction angle where i raised to a power means that the angle depends on the number of flexible elastic fastening elements and it has only one value;

F_τ^e – is friction force

$$F_\tau^e = f\begin{bmatrix}(G\cos(\psi_0 + \upsilon_0)\cos\theta - I_{ez}) + \\ + F'_{вx}\sin(\psi_0 + \vartheta_0) + (I_n + F'_{вy})\sin\theta + \sum_{i=1}^{n_p} R0_{iz}\end{bmatrix} \tag{10}$$

where f – is sliding friction coefficient ($f = 0{,}7 f_{сц}$ taking into account that $f_{сц}$ – is cohesion friction coefficient between contacting surfaces of cargo and wagon floor(taken according to reference data.);

ψ_0 и ϑ_0 – is track gradient (the angle of ascend and the angle of descend in relation to the horizontal line) and the angle of „yawing" of the wagon with cargo in case of emergency or service braking of the train moving both on a curve and a tangent and also in case of impacting of wagons in the hump yard.

In expression (8) „shearing" and „retaining" forces are equal

$$F_{сд.x} = I_{ex} + G\sin(\psi_0 + \upsilon_0)\,;\quad F_{уд.ix} = \sum_{i=1}^{n_p} R0_{ix} + F'_{вx}\cos(\psi_0 + \vartheta_0) \tag{11}$$

In expression (9) „shearing" nd „retaining" forces are equal

$$F_{сд.y} = I_{ey} + (I_n + F'_{вy})\cos\theta\,;\quad F_{уд.iy} = G\sin\theta + \sum_{i=1}^{n_p} R0_{iy}. \tag{12}$$

On the basis of the value of cargo shear in the plane of the wagon floor (Δs) we find tension R_i in i-x flexible elastic fastening elements according to the formula

$$R_i = \Delta s \cdot 7.854 d_i^2 \cdot \sum_{i=1}^{n_p} \frac{n_i}{l_i} B_i \le [R_i] \tag{13}$$

where [ΔR] – is the admissible value of tension in fastening defined according to specification for cargo placement and fastening in wagons and containers depending on the number of threads n_i and diameter d_i of fastening wire.

Under the action of spatial forces systems R_i in i-flexible elastic fastening element on the system „wagon-cargo-fastening" it is necessary to find according to the formula (13) only for those fastening elements the final length of which l_{ki} is larger than the original l_i

Statement 3. Cargo shear in relation to the wagon occurs (i.e. Δs > 0) only when $\Delta F^{(i)}$ > 0.

Statement 4. Break of flexible elastic fastening elements doesn't' happen only when the condition Δs ≤ [Δs] is observed where [Δs] – is the admissible value of shear cargo defined according to the value (mm) [ΔR].

4. CONCLUSION

Analyzing the received results of mathematical modelling of cargo fastening in a wagon it is necessary to note that for the first time there have been derived generalized formulas for defining cargo shear and tension in flexible elastic fastening elements under the action on mechanical system „wagon-cargo-fastening" of spatial forces systems. The deduced formulas take into account physic-geometrical characteristics of elastic elements (i. e. E, n, d, l), the values of external forces ($\overline{G}$, $\bar{I}_{ex}$, $\bar{I}_{ey}$, $\bar{I}_{ez}$, $\overline{F}_{в}$), received by the fastenings and cargo and the condition of contacting surfaces of cargo and wagon floor by means of friction coefficient. The derived analytical formulas serve for assessing rolling stock movement safety with asymmetrical and symmetrical allocation of cargo centre- of –mass both lengthwise and crosswise the wagon as a mechanical system „wagon-cargo-fastening".

The results of the research can be looked upon as an important contribution in the theory of cargo allocation and cargo fastening and are practically oriented making it possible to work out a program for calculation cargo fastening in a wagon using computing aids.

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Received 21.01.2008; accepted in revised form 25.09.2008