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Evaluation of strength of carrying metal structures of trailers

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ABSTRACT

Purpose: Development of a computational model of stress-strain state bearing elements of trailer frames for preliminary assessment and identification of areas with increased risk of failure.

Design/methodology/approach: The object of the study is the processes of loading the load-bearing metal structures of trailers - fertilizer spreaders. The stress-strain state of the spreader bearing system is investigated for the established three typical cases of external load. To refine the values obtained as a result of modelling, they were determined in SOLIDWORKS.

Findings: Computational models of load have been compiled by improving the method of minimum potential deformation energy for its effective correct use in analytical studies of a similar type of metal structures. It is proved that for a flat closed frame structure made of thin-walled profiles, loaded with forces perpendicular to the plane of the frame, the levelling of compression and shear energies, as well as axial and transverse forces and bending moments in the horizontal plane does not significantly affect the calculation results.

Research limitations/implications: Horizontal components of the shear forces as well as the normal forces and as a consequence the corresponding potential deformation energy are neglected, which has some effect on the accuracy of the calculations.

Practical implications: An effective tool for strength analysis with preliminary assessment and diagnostics of load-bearing metal structures based on the constructed calculation models of stress strain state load-bearing frames of typical geometry with an arbitrarily given distribution of external load.

Originality/value: A universal algorithm for recording additive functions of bending and torques, as well as the potential deformation energy of welded frames of trailers.

Keywords: Trailer, Strength, Design model, Metal construction, Bearing frame, Potential of minimum potential energy, Stress strain state

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1. Introduction

Studies of the tractor trailer reliability of types MMZ-771B and MMZ-768B were carried out taking into account the data of experimental tests at machine-testing stations in the amount of 2000 hours during transport works, including 3500 cycles of loading and unloading, which is 50% of the operating time provided by the technical conditions [1]. Obviously, the organization of transport operations at the Ministry of Internal Affairs is not identical to the actual operating conditions, all this affects the reliability indicators: for example, the readiness coefficients and the average failure time increase, the failure rate parameter decreases, etc. Moscow V.P. Goriachkin Institute of Agricultural Engineers and the Orsk Factory of Tractor Trailers conducted research on the operational reliability of the MMZ-771B and MMZ-771 semi-trailers, the MMZ-768B and MMZ-768 trailers and semi-trailers. 47 MMZ-771 semi-trailers and 15 MMZ-771B semi-trailers were under surveillance, as well as 13 MMZ-768 trailers and 7 MMZ-768B trailers manufactured by various enterprises. Trailers were operated throughout the year. They were engaged in the transportation of mineral and organic fertilizers, other bulk and bulk cargo. The tables show the average failure time of the basic elements of these trailers [1-3].

Table 1 presents data on the average operating time for failure of the main elements of trailers and the percentage of failures during operation of 4000 hours.

Therefore, the components that are subject to variable loads (bearing system, suspension) have insufficient resources: the failure rate is 50%-80%. Of all the units, special attention is paid to the frame, it, being the basic unit of the trailer (12%-48% of the weight of the agricultural machine), limits the durability of the trailer as a whole [4]. Table 2 systematizes information on the reliability of individual trailers at operating times of 0-4000 hours. The most characteristic failures of the bearing systems of all models of transport agricultural machines are cracks in the welded joints of frames [1-3], deformation and cracks of the drawbar, spars and bar. From the Table 2, in almost all trailers, the load-bearing system with a running time of 22-30% of the service life before overhaul, has a failure. Many reasons for the transition of a metal structure to a failure state make it possible to conclude a cause and effect complex of events that cause failures. The dominant causes of metal failure are manufacturing defects and design errors, the total failure rate caused by insufficient design quality can reach more than 60% [5-9].

Table 1.
The average operating time for the failure of the main elements of trailers

The average operating time for failure of MMZ-771E and the percentage of elements that failed (in parentheses)						
Frame	Pendant	Chassis	Brakes	Hydraulics	Electrical equipment	Body
391 (100%)	436 (100%)	373 (100%)	528 (66%)	467 (73%)	473 (86%)	240 (100%)
The average operating time for failure of MMZ-771E and the percentage of elements that failed (in parentheses)						
Frame	Pendant	Chassis	Brakes	Hydraulics	Electrical equipment	Body
437 (80%)	400 (53%)	335 (93%)	512 (49%)	406 (80%)	695 (35%)	284 (100%)
The average operating time for failure of MMZ-771E and the percentage of elements that failed (in parentheses)						
Frame	Pendant	Chassis	Brakes	Hydraulics	Electrical equipment	Body
753 (77%)	789 (53%)	514 (100%)	646 (85%)	785 (100%)	820 (100%)	302 (100%)

Table 2.
Reliability indicators of trailers bearing systems

	Characteristic	MMZ-77IB	MMZ-77I	MMZ-768B	MMZ-768
1	Average failure time, h	545	833	1176	889
2	The average number of failures per 1 trailer while running 4000 hours	7.34	4.8	3.4	4.5
3	Percentage of trailers that had refusals	100	85	77	100

Fig. 1. Trailer – spreader of type RTD: general view of the bearing system

Analysis of the causes of brittle fracture of metal structures [8-13] revealed a significant impact of corrosion damage [14] given the frequency of their occurrence in emergency conditions, taking into account corrosion – fatigue failure of materials from which the elements of supporting metal structures of tractor trailers associated with stress concentration and the development of corrosion – fatigue cracks. The design of load-bearing systems of trailers with the assessment of stress-strain state (SSS), service life, will achieve a good effect when conducting at the appropriate level of load-bearing capacity analysis of load-bearing metal structures based on analytical studies of SSS structural elements of the entire structure. It is necessary to develop an effective tool for strength analysis with preliminary assessment and diagnosis of load-bearing metal structures of trailers.

2. Methodology of research

The object of study is the load processes of load-bearing metal structures of trailers – fertilizer spreaders. When drawing up the calculation model, it is taken into account that the structurally bearing structure of the frame of the type RTD trailed fertilizer spreader consists of eight closed circuits and is 24 times statically indeterminate. Eight symmetrically arranged closed contours relative to the longitudinal axis were investigated with the help of an analytical bar, Figure 1b. taking into account longitudinal symmetry and external load, three conditional parts, I and II – a parts, respectively, left and right spars, and III – a central beam (Fig. 1) are considered. In each adjacent cross section of the frame element there are equal in magnitude and opposite in directions internal force factors, Mi – bending moments, Ki – torques, Qi – transverse forces.

Axial forces, bending moments and lateral forces in the horizontal plane are neglected due to the small numerical values obtained in the calculations. The creation of new analytical models of SSS bearing structures of trailers – spreaders of the studied type is complicated by the fact that structural systems are characterized by simultaneous static uncertainty in relation to external supports, as well as internal force factors [15-22]. In analytical studies of SSS, this factor is taken into account that the external loads of the load-bearing elements are non-stationary. It is known that by classical methods of estimation of the SSS of complex planar spatially loaded structural systems, a similar problem is solved with considerable errors, accepting a number of simplifications on the basis of which two tasks are consistently solved: the first is the determination of external force factors, the second is the determination of internal force factors [23-28]. The solution of these problems on a PC using known software packages provides calculations of numerical values of internal power factors without the possibility of estimating the processes occurring in the structural elements of the metal structure of the trailer, which is provided exclusively by forming a SSS model.

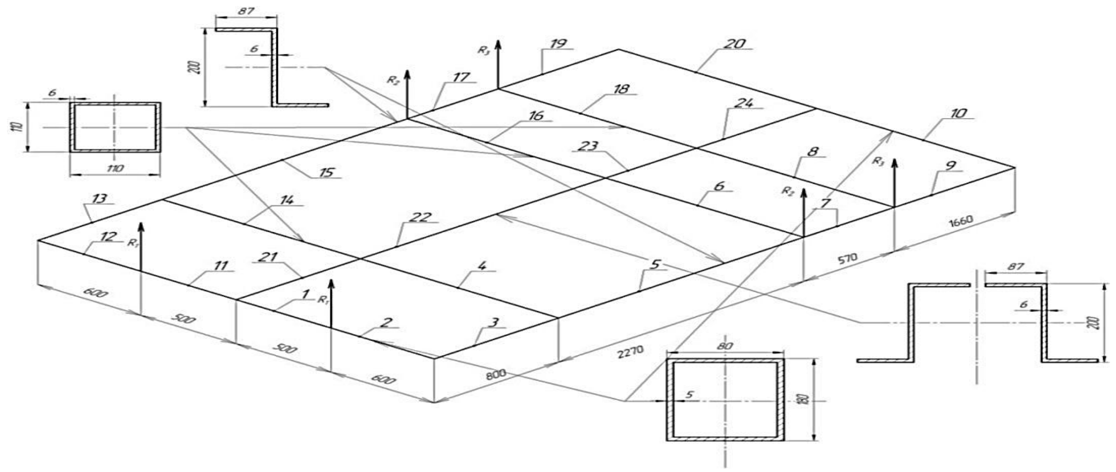

Fig. 2. Calculation scheme of trailer bearing system: where 1,2,4,6 – spars; 3 – centre beam; 5,7 – a crossbeam

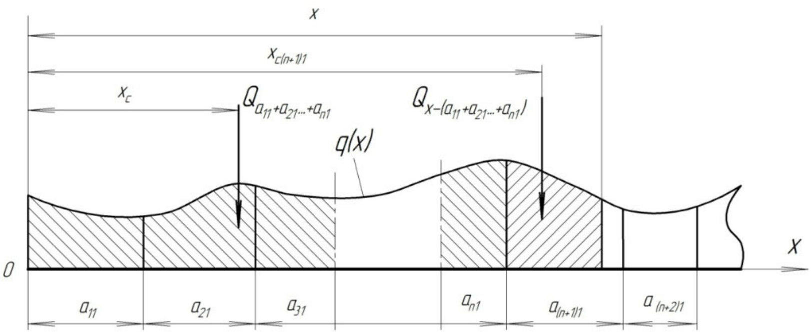

Fig. 3. Geometric interpretation to the formation of the functions of bending moments

3. Results and discussion

Three, relative to longitudinal axis of symmetry, sections of the frame structure are investigated. For any quantities, geometric as well as physical, in the notation, the index "1" indicates the order of magnitude, the index "2" indicates the part of the frame structure to which the given value belongs (for example R12 reaction force at point 1, acting on the 2nd part of the frame).

External load frame Q0 = QD + QM = 135000H, where QD = 135000H – weight of cargo, QM = 35000H – net – weight of trailer

$$Q_0 = \int_0^B q_{11}(x)dx + \int_0^A q_{21}(x)dx + \int_0^A q_{31}(x)dx + \\ + \int_0^B q_{12}(x)dx + \int_0^A q_{22}(x)dx + \int_0^B q_{31}(x)dx + \\ + \int_0^B q_{32}(x)dx + \int_0^B q_{13}(x)dx = 135000H, \qquad (1)$$

where $q_{ij}(x)$ are the functions of the load intensity of the elements: two spars, respectively, sections 1 and 2 and the Central beam, respectively, section 3, A, B-line of contact, along the outer perimeter of the frame, the body of the machine directly with the metal frame.

Recording of functions of bending moments with determination of equivalent forces and moments from arbitrary loading [26], Figure 2. The function of bending moment on the site $(a_{11}+ a_{21}+...+ a_{n1}) \le x \le (a_{11}+ a_{21}+...+$ an1+ a(n+1)1), Figure 3 [29,30].

In relation to external support reactions, the system is three times statically indeterminate [29-31], where R11, R21, R31, R12, R22, R32 – external vertical support reactions in the areas of the snitch and the axles of the trailer wheels.

In modelling, to determine the internal force factors [27, 29], the frame is conditionally cut into pieces (Fig. 4), resulting in each of the compatible cross sections of the element there are equal in magnitude and opposite directions of internal forces, such as M11 = M13 (1), M12 = M13 (2), etc.

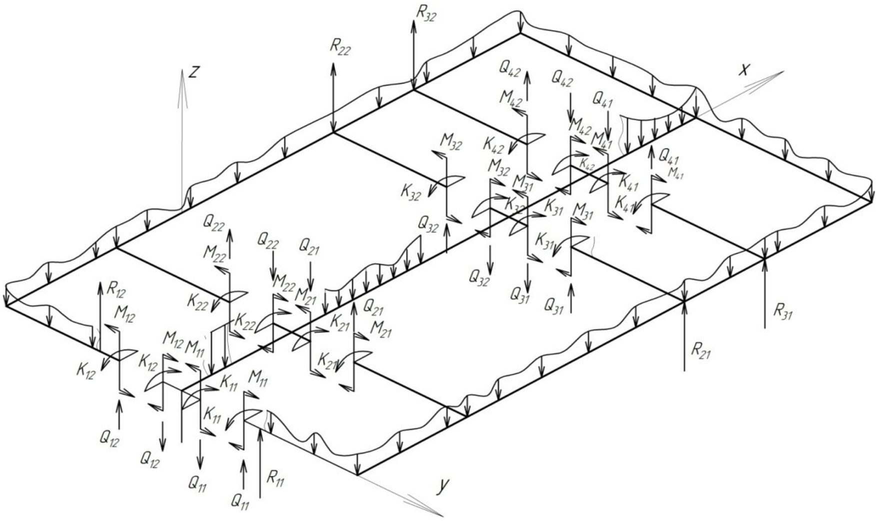

Fig. 4. Load of a metalwork of a bearing frame of a trailed spreader

$$M(x)=\int_{0}^{a_{11}+a_{21}+\ldots+a_{n1}} q(x)\cdot dx\cdot\left(x-\frac{\int_{0}^{a_{11}+a_{21}+\ldots+a_{n1}} q(x)\cdot x\, dx}{\int_{0}^{a_{11}+a_{21}+\ldots+a_{n1}} q(x)\, dx}\right)+\int_{a_{11}+a_{21}+\ldots+a_{n1}}^{x} q(x)\cdot dx\cdot\left(x-\frac{\int_{a_{11}+a_{21}+\ldots+a_{n1}}^{x} q(x)\cdot x\, dx}{\int_{a_{11}+a_{21}+\ldots+a_{n1}}^{x} q(x)\, dx}\right), \tag{2}$$

The method of minimum potential energies was used for calculation. For such flat spatially loaded metal structures, the use of other methods is impractical, requires cumbersome mathematical transformations with the construction of additional, intermediate, auxiliary plots of internal force factors. From records of functions of internal efforts by this method it is possible to understand that are the reasons of the investigated stress-deformed state.

The horizontal components of the shear forces, the normal forces and the corresponding potential deformation energies are neglected [31], the design is 24 times statically uncertain in relation to the internal forces.

Function of the total potential deformation energy of the frame structure

$$U=U_1+U_2+U_3, \tag{3}$$

where U1, U2, U3 – respectively, the potential deformation energies of I, II and III imaginary parts of the structural system.

Expressions of general functions of potential deformation energies from torques and bending moments, Figures 2-4 for the first part of the supporting frame:

$$U_1=\int_0^{a_{11}}\frac{\partial_X\left(Q_{11}(x)-\left(\int_0^x\frac{q_{21}}{1}dx\right)\left(x-\left(\int_0^x\frac{q_{21}(x)}{1}dx\right)\Big/\left(\int_0^x\frac{q_{21}}{1}dx\right)\right)+M_{11}\right)^2}{2EI_1}dx+$$
$$+\int_{a_{11}}^{a_{11}+a_{21}}\frac{1}{2EI_1}\partial_X\left(Q_{11}(x)-\left(\int_{a_{11}}^x\frac{q_{21}}{1}dx\right)\left(x-\left(\int_{a_{11}}^x\frac{q_{21}(x)}{1}dx\right)\Big/\left(\int_{a_{11}}^x\frac{q_{21}}{1}dx\right)\right)-\right.$$
$$\left.-\left(\int_0^{a_{11}}\frac{q_{21}}{1}dx\right)\left(x-\left(\int_0^{a_{11}}\frac{q_{21}(x)}{1}dx\right)\Big/\left(\int_0^{a_{11}}\frac{q_{21}}{1}dx\right)\right)+M_{11}+R_{11}(x-a_{11})\right)^2dx+$$

$$+\int_0^{b_{11}} \frac{\partial_X \left(Q_{11}(x) - K_{11} - \left(\int_0^{a_{11}+a_{21}} \frac{q_{21}}{1}dx\right)(x) - \left(\int_0^x \frac{q_{11}}{1}dx\right)\left(x - \left(\int_0^x \frac{q_{11}(x)}{1}dx\right) \Big/ \left(\int_0^x \frac{q_{11}}{1}dx\right)\right) + R_{11}(x)\right)^2}{2EI_3} dx +$$

$$+\int_0^{a_{11}+a_{21}} \frac{\partial_X (Q_{21}(x)+M_{21})^2}{2EI_2}dx + \int_{b_{11}}^{b_{21}+b_{11}} \frac{1}{2EI_3}\partial_X \Bigg(\Bigg(Q_{11}(x)+R_{11}(x)-K_{11}+Q_{21}(x-b_{11})-K_{21}-\left(\int_0^{a_{11}+a_{21}}\frac{q_{21}}{1}dx\right)(x)-$$

$$-\left(\int_0^{b_{11}}\frac{q_{11}}{1}dx\right)\left(x-\left(\int_0^{b_{11}}\frac{q_{11}(x)}{1}dx\right)\Big/\left(\int_0^{b_{11}}\frac{q_{11}}{1}dx\right)\right)-\left(\int_{b_{11}}^x\frac{q_{11}}{1}dx\right)\left(x-\left(\int_{b_{11}}^x\frac{q_{11}(x)}{1}dx\right)\Big/\left(\int_{b_{11}}^x\frac{q_{11}}{1}dx\right)\right)\Bigg)\Bigg)^2 dx+$$

$$+\int_0^{a_{11}+a_{21}}\frac{\partial_X(Q_{31}(x)+M_{31})^2}{2EI_2}dx+\int_{b_{11}+b_{21}}^{b_{31}+b_{21}+b_{11}}\frac{1}{2EI_3}\partial_X(((Q_{11}(x)+R_{11}(x)-K_{11}-\left(\int_0^{a_{11}+a_{21}}\frac{q_{21}}{1}dx\right)(x)-$$

$$-\left(\int_0^{b_{11}+b_{21}}\frac{q_{11}}{1}dx\right)\left(x-\left(\int_0^{b_{11}+b_{21}}\frac{q_{11}(x)}{1}dx\right)\Big/\left(\int_0^{b_{11}+b_{21}}\frac{q_{11}}{1}dx\right)\right)-\left(\int_{b_{11}+b_{21}}^x\frac{q_{11}}{1}dx\right)\cdot$$

$$\cdot\left(x-\left(\int_{b_{11}+b_{21}}^x\frac{q_{11}(x)}{1}dx\right)\Big/\left(\int_{b_{11}+b_{21}}^x\frac{q_{11}}{1}dx\right)\right)+Q_{21}(x-b_{11})-K_{21}+Q_{31}(x-b_{11}-b_{21})-K_{31}+$$

$$+R_{21}(x-b_{11}-b_{21})))^2\Big)dx+\int_0^{a_{11}+a_{21}}\frac{\partial_X(Q_{41}(x)+M_{41})^2}{2EI_2}dx+\int_{b_{11}+b_{21}+b_{31}}^{b_{41}+b_{31}+b_{21}+b_{11}}\frac{1}{2EI_3}\partial_X((Q_{11}(x)+R_{11}(x)-K_{11}-$$

$$-\left(\int_0^{a_{11}+a_{21}}\frac{q_{21}}{1}dx\right)(x)-\left(\int_0^{b_{11}+b_{21}+b_{31}}\frac{q_{11}}{1}dx\right)\left(x-\left(\int_0^{b_{11}+b_{21}+b_{31}}\frac{q_{11}(x)}{1}dx\right)\Big/\left(\int_0^{b_{11}+b_{21}+b_{31}}\frac{q_{11}}{1}dx\right)\right)-$$

$$-\left(\int_{b_{11}+b_{21}+b_{31}}^x\frac{q_{11}}{1}dx\right)\left(x-\left(\int_{b_{11}+b_{21}+b_{31}}^x\frac{q_{11}(x)}{1}dx\right)\Big/\left(\int_{b_{11}+b_{21}+b_{31}}^x\frac{q_{11}}{1}dx\right)\right)+Q_{21}(x-b_{11})-K_{21}+Q_{31}(x-b_{11}-b_{21})-$$

$$-K_{31}+R_{21}(x-b_{11}-b_{21})+Q_{41}(x-b_{11}-b_{21}-b_{31})-K_{41}+R_{31}(x-b_{11}-b_{21}-b_{31}))^2\Big)dx+$$

$$+\int_0^{a_{11}+a_{21}}\frac{1}{2EI_1}\partial_X(((Q_{11}(x)-Q_{11}(a_{11}+a_{21})+R_{11}(x)-R_{11}(a_{21})-M_{11}+Q_{21}(x)-Q_{21}(a_{11}+a_{21})-M_{21}+$$

$$+Q_{31}(x)-Q_{31}(a_{11}+a_{21})-M_{31}+R_{21}(x)+Q_{41}(x)-Q_{41}(a_{11}+a_{21})-M_{41}+R_{31}(x)-$$

$$-\left(\int_0^{b_{11}+b_{21}+b_{31}+b_{41}}\frac{q_{11}}{1}dx\right)(x)-\left(\int_0^x\frac{q_{31}}{1}dx\right)\left(x-\left(\int_0^x\frac{q_{31}(x)}{1}dx\right)\Big/\left(\int_0^x\frac{q_{31}}{1}dx\right)\right)-\left(\int_0^{a_{11}+a_{21}}\frac{q_{21}}{1}dx\right)(x)+$$

$$+\left(\int_0^{a_{11}+a_{21}}\frac{q_{21}}{1}dx\right)\left(a_{11}+a_{21}-\left(\int_0^{a_{11}+a_{21}}\frac{q_{21}(x)}{1}dx\right)\Big/\left(\int_0^{a_{11}+a_{21}}\frac{q_{21}}{1}dx\right)\right)\Bigg)\Bigg)^2dx+\int_0^{a_{11}+a_{21}}\frac{\partial_X(K_{11})^2}{2GIk_1}dx+$$

$$+\int_0^{b_{11}}\frac{\partial_X\left(Q_{11}(a_{11}+a_{12})+R_{11}(a_{21})+M_{11}-\left(\int_0^{a_{11}+a_{21}}\frac{q_{21}}{1}dx\right)\left(a_{11}+a_{21}-\left(\int_0^{a_{11}+a_{21}}\frac{q_{21}(x)}{1}dx\right)\Big/\left(\int_0^{a_{11}+a_{21}}\frac{q_{21}}{1}dx\right)\right)\right)^2}{2GIk_3}dx+$$

$$+\int_0^{a_{11}+a_{21}}\frac{\partial_X(K_{21})^2}{2GIk_2}dx+\int_0^{a_{11}+a_{21}}\frac{\partial_X(K_{31})^2}{2GIk_2}dx+\int_{b_{11}}^{b_{11}+b_{21}}\frac{\partial_X(Q_{11}(a_{11}+a_{12})+R_{11}(a_{21})+M_{11}}{2GIk_3}-$$

$$-\frac{\left(\int_0^{a_{11}+a_{21}}\frac{q_{21}}{1}dx\right)\left(a_{11}+a_{21}-\left(\int_0^{a_{11}+a_{21}}\frac{q_{21}(x)}{1}dx\right)\Big/\left(\int_0^{a_{11}+a_{21}}\frac{q_{21}}{1}dx\right)\right)+Q_{21}(a_{11}+a_{21})+M_{21})^2}{2GIk_3}dx+$$

$$
\begin{gathered}
+\int_0^{a_{11}+a_{21}} \frac{\partial_X \left(K_{41}\right)^2}{2GIk_2}\,dx+\int_{b_{11}+b_{21}}^{b_{11}+b_{21}+b_{31}} \frac{1}{2GIk_3}\,\partial_X \biggl(Q_{11}\left(a_{11}+a_{21}\right)+R_{11}\left(a_{21}\right)+M_{11}-\left(\int_0^{a_{11}+a_{21}}\frac{q_{21}}{1}\,dx\right)\times \\
\times\Biggl(a_{11}+a_{21}-\left(\int_0^{a_{11}+a_{21}}\frac{q_{21}(x)}{1}\,dx\right)\Bigg/\left(\int_0^{a_{11}+a_{21}}\frac{q_{21}}{1}\,dx\right)\Biggr)+Q_{21}\left(a_{11}+a_{21}\right)+M_{21}+Q_{31}\left(a_{11}+a_{21}\right)+M_{31}\biggr)^2 dx+ \\
+\int_{b_{11}+b_{21}+b_{31}}^{b_{11}+b_{21}+b_{31}+b_{41}} \frac{1}{2GIk_3}\,\partial_X \biggl(Q_{11}\left(a_{11}+a_{21}\right)+R_{11}\left(a_{21}\right)+M_{11}-\left(\int_0^{a_{11}+a_{21}}\frac{q_{21}}{1}\,dx\right)\cdot \\
\cdot\Biggl(a_{11}+a_{21}-\left(\int_0^{a_{11}+a_{21}}\frac{q_{21}(x)}{1}\,dx\right)\Bigg/\left(\int_0^{a_{11}+a_{21}}\frac{q_{21}}{1}\,dx\right)\Biggr)+Q_{21}\left(a_{11}+a_{21}\right)+M_{21}+Q_{31}\left(a_{11}+a_{21}\right)+M_{31}+ \\
Q_{41}\left(a_{11}+a_{21}\right)+M_{41}\biggr)^2 dx+\int_0^{a_{11}+a_{21}}\frac{1}{2GIk_1}\partial_X \biggl(\bigl(Q_{11}\left(b_{11}+b_{21}+b_{31}+b_{41}\right)+R_{11}\left(b_{11}+b_{21}+b_{31}+b_{41}\right)-K_{11}- \\
-\left(\int_0^{a_{11}+a_{21}}\frac{q_{21}}{1}\,dx\right)\left(b_{11}+b_{21}+b_{31}+b_{41}\right)-\left(\int_0^{b_{11}+b_{21}+b_{31}+b_{41}}\frac{q_{11}}{1}\,dx\right)\Bigl(b_{11}+b_{21}+b_{31}+b_{41}- \\
-\left(\int_0^{b_{11}+b_{21}+b_{31}+b_{41}}\frac{q_{11}(x)}{1}\,dx\right)\Bigg/\left(\int_0^{b_{11}+b_{21}+b_{31}+b_{41}}\frac{q_{11}}{1}\,dx\right)\Bigr)+Q_{21}\left(b_{21}+b_{31}+b_{41}\right)-K_{21}+Q_{31}\left(b_{31}+b_{41}\right)- \\
-K_{31}+R_{21}\left(b_{31}+b_{41}\right)+R_{31}\left(b_{41}\right)+Q_{41}\left(b_{41}\right)-K_{41}\bigr)^2\biggr)dx \qquad (4)
\end{gathered}
$$

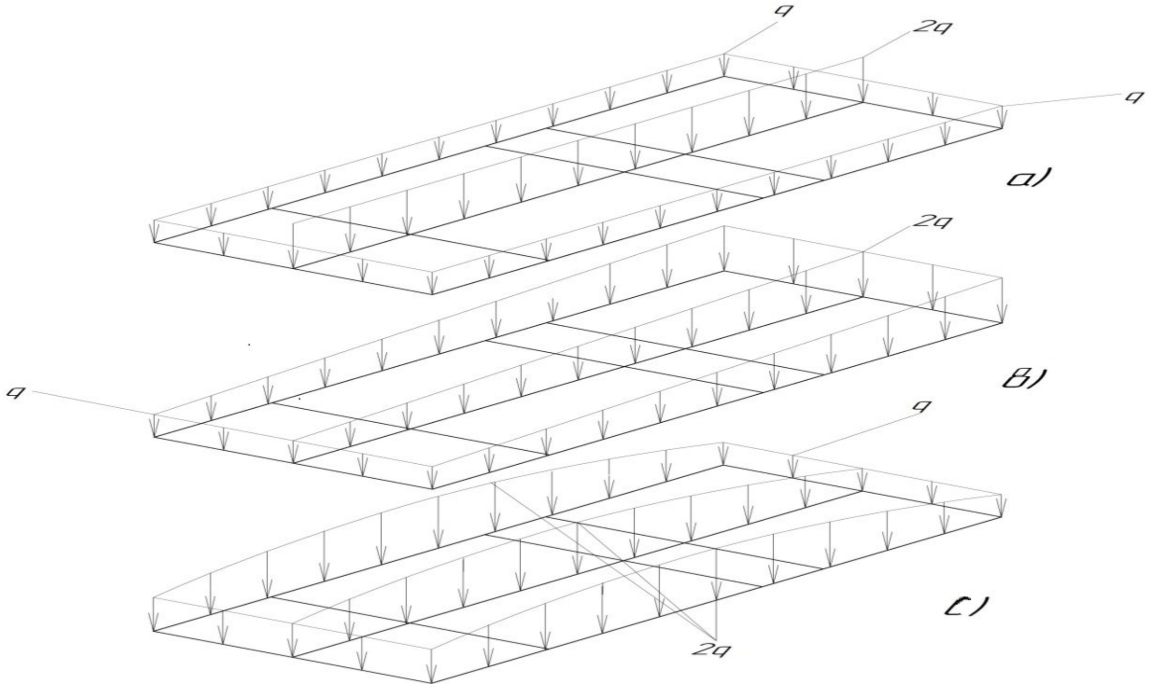

Fig. 5. Schematic diagram of the load on the carrier frame of the trailer

Expressions for all parts of a frame metalwork are similarly written down. These calculations will be useful primarily for machines with flat spatially loaded load-bearing frames.

SSS of the spreader bearing system is investigated for the established three typical cases of external loading (Fig. 5). From (1) the magnitude of the load intensity for these cases was determined (Fig. 5). The results are given in Table 3. According to the composite model of SSS (3), (4) the internal force factors in the cross sections of the trailer frame were determined (Tab. 3). To clarify the values obtained as a result of simulation, they are defined in SOLIDWORKS

(Fig. 6). Therefore, it is established that the dangerous section of the frame structure is the area of the spar to which the axis of the support wheels is attached, Figure 7.

The correlation of the obtained values according to the calculations (Tab. 4) is good.

Taking into account the geometry of the investigated section (Fig. 7), the values of maximum stresses and actual safety margins were calculated [30]. The results are presented in Table 5. The results obtained are satisfactorily correlated with those obtained in the calculations in SOLIDWORKS.

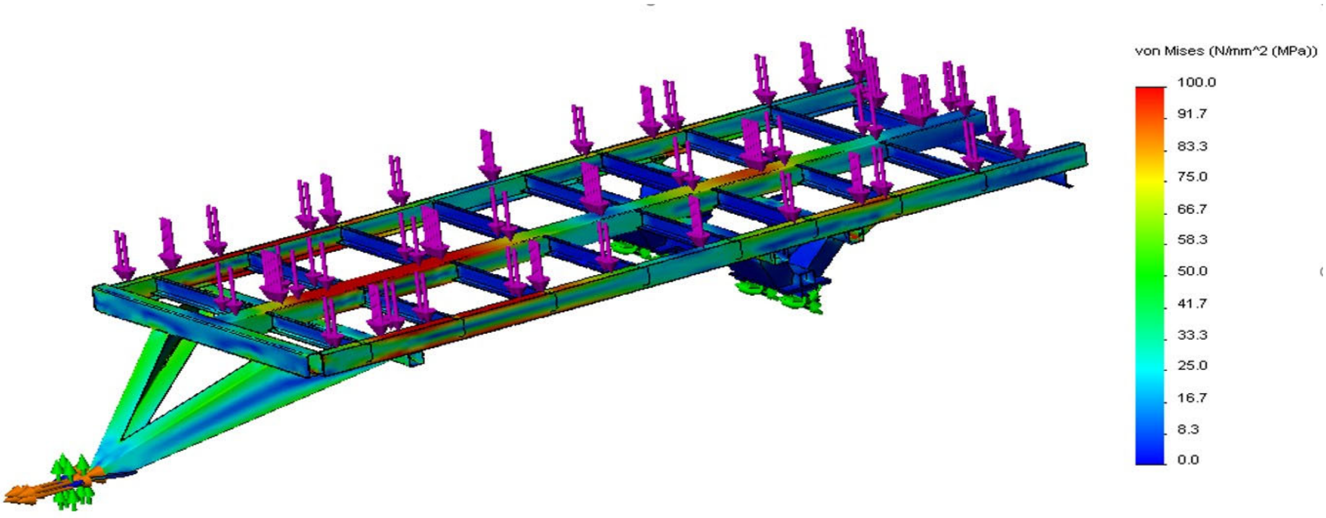

Fig. 6. Stress strain state of the bearing frame of the RTD – 9 trailer – spreader

Table 3.
Internal power factors in the elements of metal construction

#	Effort	Load schematization, Fig. 5a	Load schematization, Fig. 5b	Load schematization, Fig. 5c
1	$q_{11}(x)$	q	q+q x/5.3	$((-4q/B^2)(x-B/2)^2+2q)$
2	$q_{21}(x)$	q	q	q
3	$q_{31}(x)$	q	2q	q
4	$q_{12}(x)$	q	q+q x/5.3	$((-4q/B^2)(x-B/2)^2+2q)$
5	$q_{22}(x)$	q	q	q
6	$q_{32}(x)$	q	2q	q
7	$q_{13}(x)$	2q	q+q x/5.3	$((-4q/B^2)(x-B/2)^2+2q)$
8	q, N/m	5275	4434	4703
9	R_{11}, N	19177	13955	17775.4
10	R_{21}, N	-5190	-21904.1	20331
11	R_{31}, N	53533	75449.2	70056.3
12	R_{12}, N	19177	13955	17775.4
13	R_{22}, N	-5190	-21904.1	20331
14	R_{32}, N	53533	75449.2	70056.3
15	M_{11}, Nm	-593.354	-1991.31	-2160.56

#	Effort	Load schematization, Fig. 5a	Load schematization, Fig. 5b	Load schematization, Fig. 5c
16	M_{21}, Nm	486.45	-1337.51	-2555.43
17	M_{31}, Nm	9460.94	7255.29	2951.73
18	M_{41}, Nm	10943	10196.7	5000.01
19	K_{11}, Nm	-526.241	-104.678	82.7678
20	K_{21}, Nm	-716.776	-262.522	0.880326
21	K_{31}, Nm	-860.837	-1429.59	-1067.83
22	K_{41}, Nm	-111.185	-577.656	-280.423
23	Q_{11}, N	-7015.44	-3361.46	-5144
24	Q_{21}, N	-441.412	1219.24	2325.84
25	Q_{31}, N	-8602.54	-6594.04	-2681.96
26	Q_{41}, N	-9957.38	-9281.41	-4550.28
27	M_{12}, Nm	-593.354	-1991.31	-2160.56,
28	M_{22}, Nm	486.45	-1337.51	-2555.43
29	M_{32}, Nm	9460.94	7255.29	2951.73
30	M_{42}, Nm	10943	10196.7	5000.01
31	K_{12}, Nm	-526.241	-104.678	82.7678
32	K_{22}, Nm	-716.776	-262.522	0.880326
33	K_{32}, Nm	-860.837	-1429.59	-1067.83
34	K_{42}, Nm	-111.185	-577.656	-280.423
35	Q_{12}, N	-7015.44	-3361.46	-5144
36	Q_{22}, N	-441.412	1219.24	2325.84
37	Q_{32}, N	-8602.54	-6594.04	-2681.96
38	Q_{42}, N	-9957.38	-9281.41	-4550.28

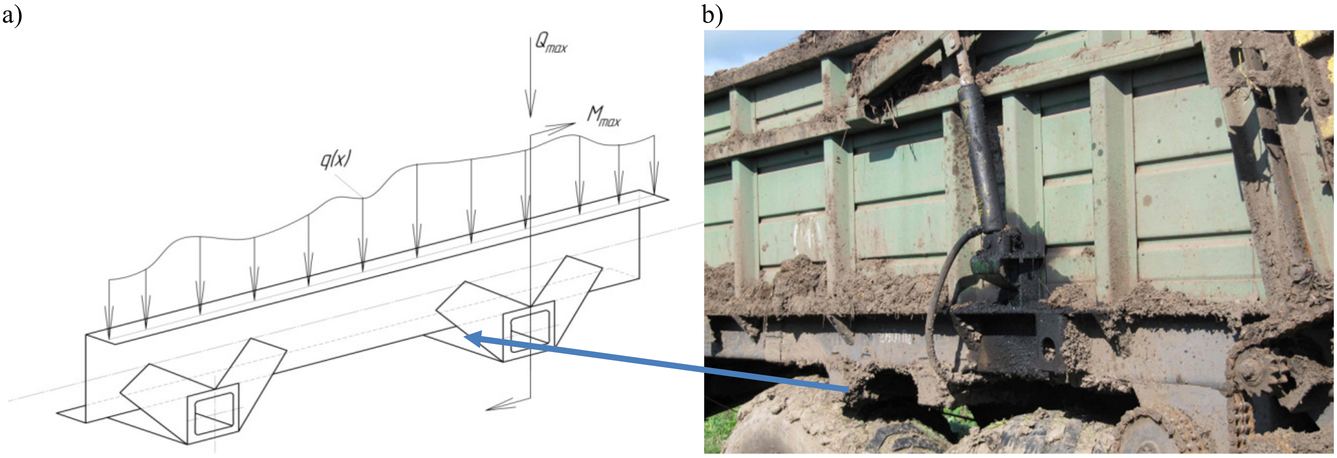

Fig. 7. Dangerous section of the frame structure

Table 4.
The results of calculations of internal forces in the bearing system RTD – 9

Stress Factor	M_1, Nm	M_2, Nm	M_3, Nm	M_4, Nm	K_1, Nm	K_2, Nm	K_3, Nm	K_4, Nm	Q_1, N	Q_2, N	Q_3, N	Q_4, N
Model calculation	593.354	486.45	9460.94	10943	526.241	716.776	860.837	111.185	7015.44	441.412	8602.54	9957.38
SOLIDWORKS	541	548	10200	11010	590	687	871	101	7600	410	8298	9388

Table 5.
SSS of the most loaded element of the spreader metal structure

#	Loading scheme	$M_{\max}$, Nm	$\sigma_{\max}$, MPa	$Q_{\max}$,N	σ_A, MPa	τ_A, MPa	σ_{br}^{IV}, MPa	n_T
1	Fig. 5a	18808	93.8	27075	90	11.5	92.2	2.60
2	Fig. 5b	26277	131.0	43299	125.7	18.4	129.7	1.85
3	Fig. 5c	28283	141.0	43103	135.3	18.3	139.0	1.73

4. Conclusions

For the purpose of preliminary estimation of SSS of frame structures of type RTD trailers, computational load models have been compiled by improving the method of minimum potential energy of deformation for its effective correct use in analytical studies of a similar type of metal structures. It is proved that for a flat closed frame structure of thin-walled profiles loaded with forces perpendicular to the plane of the frame, the levelling of the compression and shear energies, as well as the axial and lateral forces and bending moments in the horizontal plane does not significantly affect the results. A universal algorithm for recording additive functions of bending and torques, as well as the potential deformation energy of welded frames of RTD trailers has been developed. An effective tool for strength analysis with preliminary estimation and diagnostics of load-bearing steel structures based on the calculated SSS models of trailer frame elements has been developed. The effectiveness of the proposed approaches and models in the calculation of load-bearing frames of typical geometry with an arbitrarily given distribution of external load is proved by comparing the results with calculated in SOLIDWORKS with quantitative and qualitative characteristics of SSS load-bearing RTD -9 metal structure trailer

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