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DEVISING A PROCEDURE FOR CALCULATING THE DESIGNED STRENGTH OF A KINGPIN-TYPE LOAD-CARRYING SYSTEM FOR AN ARTICULATED TRACTOR CONTAINER CARRIER

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The development of a methodology for calculating the designed strength of an unconventional kingpin-type load-carrying system for the articulated tractor container carrier on pneumatic wheels is an important and relevant task due to the unique layout of a given specialized vehicle. The purpose of this work is to devise a procedure for calculating the designed strength of a clip load-carrying system for the articulated tractor container carrier on pneumatic wheels, aimed at building an improved structure with rational metal consumption.

The results of the theoretical and experimental studies have determined the most common estimation cases. They include the movement over the technological roads' irregularities along the horizontal section of the road – an estimation case of the semi-trailer frame girders. climbing a high curb at an angle was also considered as an estimation case for the semi-trailer frame girders and cross member. Starting a tractor container carrier forward with an insurmountable obstacle in front of the semi-trailer's wheels was analyzed as an estimation case for the cross member of the frame and the suspension attachment units in the semi-trailer of a tractor container carrier.

The result of the reported theoretical and experimental research is the determined load that acts on one cradle structure of the load-carrying system; it forms the torsional rigidity of the frame structure. Underlying the derived mathematical model for each case are the torsional moments and inertia moments that act on the structural elements of the girder in different planes.

The mathematical models have been built on the basis of strength conditions for each estimation case and thus form a mathematical formula for determining the wall thickness of the frame girder. The mathematical notation demonstrates the degree of advantage of climbing a high curb at an angle over other estimation cases for the semitrailer frame member and girders.

The estimation parameters underlying the mathematical model are meant to prevent the breaking and torsion of the semi-trailer frame in a tractor container carrier

Keywords: transportation technologies, design calculation, kingpin-type frame, estimation scheme, estimated load

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1. Introduction

Underlying the proposed methodology are the most characteristic estimation cases of loading the main force elements, units, and assemblies of the kingpin-type load-carrying system of an articulated tractor container carrier.

Based on the results of our theoretical and experimental research, the following estimation cases can be distinguished:

1) a movement over the irregularities of technological roads along a horizontal section of the road – an estimation case of the semi-trailer frame girders;

2) climbing a high curb at an angle – an estimation case of the semi-trailer frame girders and member;

3) starting a tractor container carrier forward with an insurmountable obstacle in front of the semi-trailer wheels – an estimation case of the frame cross member and the suspension attachment units in the semi-trailer of a tractor container carrier. It is known that the type of force elements' profile affects the torsional rigidity of load-carrying systems, which significantly influences the formation of external loads, the perception and transmission of internal efforts when vehicles move over the irregularities of technological roads.

Depending on the layout and structural features, a particular type of profiles should be selected; this is evidenced by the examples of using open, closed, or combined profiles.

The load-carrying systems of specialized vehicles are mostly the multi-contour flat-space frames with the open profiles of their force elements. Given their nature, these systems cannot possess high torsional rigidity; when driving over the irregularities of technological roads, they are affected by these irregularities, twisted as a propeller, and undergo significant deformations.

The girder load-carrying systems, on the contrary, have an unbranched structure in the form of a central girder with the closed profile, which perceives all bending and torsional loads while the irregularities of technological roads are accepted by an elastic suspension.

The semi-trailer of a tractor container carrier with a kingpin-type frame rests on three points and, when driving over the irregularities of technological roads, is not deformed from its plane, hence, on one hand, there are no restrictions on the type of profiles of the force elements. On the other hand, suspension elements and supporting units for containers cause the occurrence of torsional moments that act on the kingpin-type frame girders. In addition, the cross member, when overcoming a frontal obstacle, is loaded with bending moments in two planes, which necessitates equipping the kingpin-type load-carrying system with the force elements with the closed profile.

The torsional stiffness of the girders significantly affects the perception and transmission of efforts in the intersections hosting the suspension attachment units. Since the suspension is considered a vertical supporting body, it is advisable to consider vertical loads only in the course of a vehicle's perturbed movement. The girders' rigidity is a longitudinal plane, which, due to the design features, rests on the suspension. Depending on the moment of applying the force load, the suspension can be calculated as a rigid or elastic load on the frame. The combined action of the resistances in the horizontal and vertical planes yields the resulting value for calculating the designed strength.

2. Literature review and problem statement

Research into the dynamics and strength of machines with a non-standard layout is a common task, though not studied in detail yet. Analysis of the strength of load-carrying systems in industrial transport underlies similar studies. Thus, work [1] studies the dynamics of self-propelled machines with a hinged frame, including the fluctuations and motion stability. However, the authors did not fully investigate an estimation case for the semi-trailer's frame girders. Paper [2] addresses choosing the type of a load-carrying system for automatic coupler with a U-shaped frame but there is no analysis of dynamic loads whatsoever.

Work [3] reports analytical research into the oscillations of the two-link systems in specialized vehicles. However, the authors failed to consider an estimation case for the semi-trailer's frame member and girders. Paper [4] examined the dynamic impact of girder oscillations during movement but there is no analysis of the horizontal components of forces acting on the girder.

Study [5] improved the work process of self-propelled loading and transporting equipment. The cited study did not consider an estimation case for the cross member in the frame and the suspension attachment units in the semi-trailer of a tractor container carrier. Work [6] reveals the effect of load forces at the surface of the rotating elements but fails to consider the effect of static loads on the rigidly fixed elements of the frame. Work [7] is an analysis of the constructive elements on the view of the viewer. Work [8] diagnosed the existing damage to mechanisms without taking into consideration the causes and theoretical analysis of these malfunctions. Paper [9] examined the vibration loads caused by the technological bodies of the units while other types of loads remained unattended. Study [10] analyzed the procedures for determining vibration loads on moving units while other methods were not considered. Paper [11] addresses to a mathematical model of the value of the parameters in the drag system, but the methodology for designing the drag system is not described.

The lack of methodological justification of the applied procedures for diagnosing and analyzing loads is the precondition for setting a task to address the issue relating to the methodological support for designing the load-carrying systems for technological specialized vehicles with an unconventional layout.

3. The aim and objectives of the study

The aim of this study is to devise a methodology for calculating the designed strength of the kingpin-type load-carrying system for an articulated tractor container carrier, which would make it possible to reduce the operational risks of frame ruptures and torsional at the design stage and to shorten the time for calculating the strength of a kingpin-type load-carrying system for an articulated tractor container carrier.

To accomplish the aim, the following tasks have been set:

– to determine a condition of strength for three estimation cases: movement over the irregularities of technological roads, climbing a high curb at an angle, and starting a tractor container carrier forward with an insurmountable obstacle in front of the wheels of a semi-trailer;

– to determine the weight of the cut-out hardness of the cross-section stabilizer of the profile of the round and round cross-overs.

4. Materials and methods to study the methodology for calculating the designed strength of a kingpin-type load-carrying system

Our study, which addresses the development of a calculation methodology, is based on the methods of analytical mechanics using a Lagrange equation of the second kind if there are indicators of dynamism, they are ready to go on the way to the end of the day, the resistance of materials using the analytical and graphic materials in the form of functions of the internal force factors and corresponding diagrams. Our results are strictly reasoned and form the basis for the practical calculation of the strength of a kingpin-type load-carrying system for an articulated tractor container carrier.

5. Results of studying the methodology for calculating the designed strength of a kingpin-type load-carrying system for an articulated tractor container carrier

5. 1. Determining a strength condition for the estimation case: a movement over the irregularities of technological roads

In the kingpin-type load-carrying system of an articulated tractor container carrier, vertical loads are formed during the perturbed movement of the machine. In the longitudinal plane, the loads are transferred to the frame girders, which rest on a suspension, rigid or elastic.

Fig. 1 shows an articulated tractor container carrier with a kingpin-type frame described in work [11].

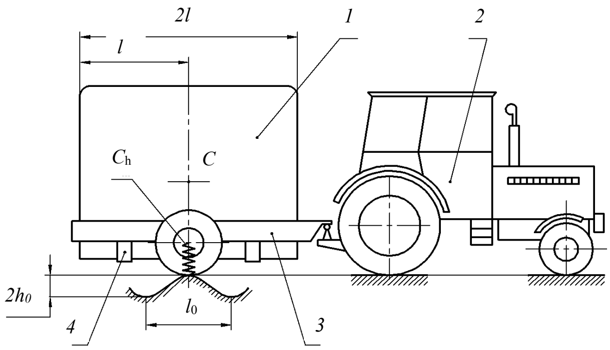

Fig. 1. An articulated tractor container carrierwith a kingpin-typeframe [11]: 1 – container; 2 – tractor; 3 – semi-trailer with a kingpin-typeframe; 4 – cradle structure

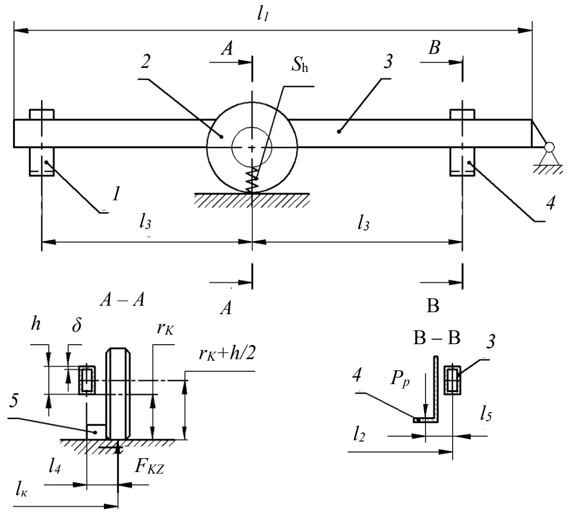

Fig. 2. The semi-trailer of a tractor container carrier with a kingpin-type frame [11]: 1 – rear cradle structure; 2 – semi-trailer's wheel; 3 – a kingpin-type frame; 4 – front cradle structure; 5 – curb

It follows from the layout of an articulated tractor container carrier that its frame rests on three points, so, when driving over the irregularities of technological roads, it does not deform from its plane. Hence, it follows that the torsional rigidity is not relevant for such a frame. On the other hand, the torsional rigidity of the girders as the longitudinal force elements of the frame, significantly affects the perception and transmission of efforts in the intersections hosting the suspension attachment units, as well as cradle structures for containers.

Fig. 2 shows the kingpin-type frame of an articulated tractor container carrier; it also demonstrates the characteristic intersections that determine the formation of loads and the transmission of efforts. The estimated scheme of a kingpin-type frame is illustrated in Fig. 3.

We determine the estimated loads P_p, which act on the cradle structure from the container. Neglecting the torsional rigidity of the container, it can be assumed that the loads are distributed evenly across the cradle structures [11]:

$$P_p = \frac{K_{\partial 1} m_k g}{4}, \tag{1}$$

where P_p is the estimated load, which acts on one cradle structure of the load-carrying system, N; $K_{\partial 1}$ is the dynamic coefficient, which corresponds to the first estimation case; m_k is the container weight, kg; g is the acceleration of free fall, m/s^2.

The dynamic coefficient $K_{\partial 1}$ should be taken as follows: $K_{\partial 1} = 2.0$ – for an elastic suspension; $K_{\partial 1} = 3.0$ – for a rigid suspension.

The l_1, l_2, l_3 sizes are set on the basis of the dimensions of containers or pallets. In addition, it should be added that in order to unload the attaching device of a semi-trailer the distance between the cradle structure and the axis should be the same, specifically l_3 (Fig. 3). In this case, the reactions of the supports at points 5 and 16 are equal to $2P_p$. Next, we record the functions of the bending and torsional moments at the characteristic sections of the frame and build appropriate diagrams of the internal force factors (Fig. 4).

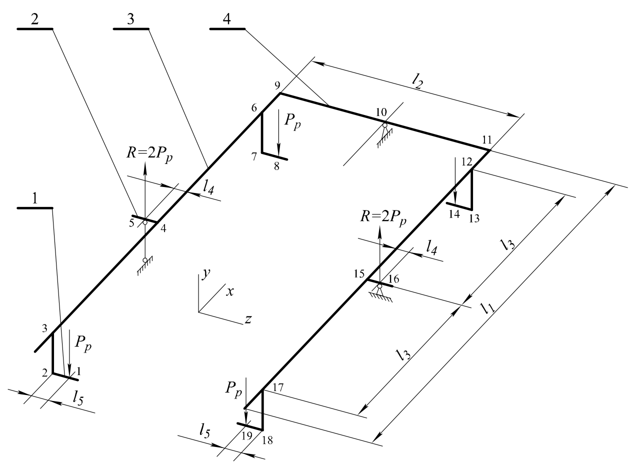

Fig. 3. Estimation scheme of the kingpin-type frame [11]: 1 – cradle structure; 2 – suspension axis; 3 – girder; 4 – frame member

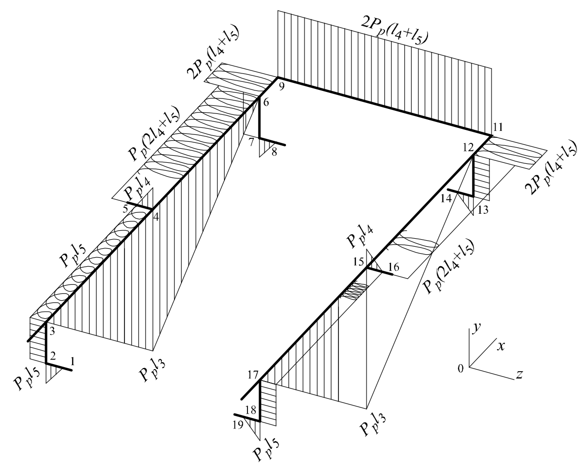

Fig. 4. Diagrams of bending and torsional moments for the first estimation case in the kingpin-type frame [11]

The diagram of bending moments.

$$M_x(z)_{1-2} = M_x(z)_{19-18} = -P_p z.$$

$$z=0,\;\; M_x=0;\;\; z=l_{1-2}=l_{19-18}=l_5,\;\; M_x-P_pl_5.$$

$$M_x(y)_{2-3}=M_x(y)_{18-17}=-P_pl_5.$$

$$M_z(x)_{3-4}=M_z(x)_{17-15}=-P_px.$$

$$x=0,\;\; M_z=0;\;\; x=l_{3-4}=l_{17-15}=l_3,\;\; M_z=-P_pl_3.$$

$$M_x(z)_{5-4}=M_x(z)_{16-15}=2P_px.$$

$$x=0,\;\; M_x=0;\;\; x=l_{5-4}=l_4,\;\; M_x=2P_pl_4.$$

$$M_z(x)_{4-6}=M_z(x)_{15-12}=-P_p(l_3-x).$$

$$x=0,\;\; M_z=-P_pl_3;\;\; x=l_{4-6}=l_{15-12}=l_3;\;\; M_z=0.$$

$$M_x(z)_{8-7}=M_x(z)_{14-13}=-P_pz.$$

$$z=0,\;\; M_x=0;\;\; z=l_{8-7}=l_{14-13}=l_5,\;\; M_x=-P_pl_5.$$

$$M_x(y)_{7-6}=M_x(y)_{13-12}=-P_pl_5.$$

$$M_z(x)_{6-9}=M_z(x)_{12-11}=0.$$

$$M_x(z)_{9-11}=2P_p(l_4+l_5).$$

The diagram of torsional moments

$$M_{kp}(z)_{1-2}=M_{kp}(z)_{19-18}=0.$$

$$M_{kp}(y)_{2-3}=M_{kp}(y)_{18-17}=0.$$

$$M_{kp}(x)_{3-4}=M_{kp}(x)_{17-15}=P_pl_5.$$

$$M_{kp}(z)_{5-4}=M_{kp}(z)_{16-15}=0.$$

$$M_{kp}(x)_{4-6}=M_{kp}(x)_{15-12}=P_p(2l_4+l_5).$$

$$M_{kp}(x)_{6-9}=M_{kp}(x)_{12-11}=2P_p(l_4+l_5).$$

$$M_{kp}(z)_{9\;\;11}\quad 0.$$

After obtaining the analytical expressions and building the diagrams of the bending and torsional moments for the first estimation case in the kingpin-type frame, we proceed to calculating the designed strength of the frame girders. Taking into consideration the joint action of the bending and torsional moments on the girders, we consider these force elements with a closed, rectangular, thin-walled profile (Fig. 5).

As shown by the diagrams of bending and torsional moments (Fig. 4), the dangerous intersections for girders are supporting intersections 4 and 15, where there is a complex stressed state. We record the strength condition for these intersections using the third theory of strength [10, 11]:

$$\sigma_{ekv}=\sqrt{\sigma^2+4\tau^2}=\sqrt{\left[\frac{M_{z(4,15)}}{W_{z(4,15)}}\right]^2+4\left[\frac{M_{kp(4,15)}}{W_{kp(4,15)}}\right]^2}\le[\sigma], \qquad (2)$$

where σ_{ekv} is the equivalent stress, Pa; $[\sigma]$ is the permissible stress, Pa; $W_{z(4,15)}$ is the moment of resistance to bending the profile of a girder in a dangerous intersection, m^3; $W_{kp(4,15)}$ is the moment of resistance to the torsion of the profile of a girder in a dangerous intersection, m^3.

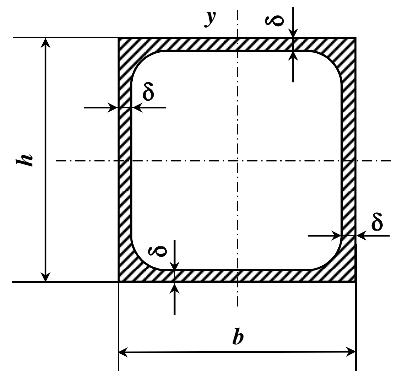

Fig. 5. Cross-section of the force elements of kingpin-type frame in a tractor container carrier

After disclosing the analytical expressions for the bending and torsional moments, as well as the geometric characteristics of dangerous intersections 4 and 15, strength condition (2) takes the following form:

$$\sigma_{ekv}=\sqrt{\left[\frac{\frac{1}{4}K_{\partial 1}m_kgl_3}{\frac{\delta h^2}{3}\left(3\frac{b}{h}+1\right)}\right]^2+4\left[\frac{\frac{1}{4}K_{\partial 1}m_kg(2l_4+l_5)}{2(b-\delta)(h-\delta)\delta}\right]^2}\le[\sigma]. \quad (3)$$

By setting two measurements of the transverse cross-section (typically, these are the outer dimensions b and h), we determine the third, namely the thickness of the walls (Fig. 5), based on the strength condition (3).

5. 2. Determining the strength condition for the estimation case: climbing a high curb at an angle

The second estimation case is the calculation of the designed strength of the frame girders and member in the kingpin-type load-carrying system when loaded by the lateral forces in the frame plane. The estimated scheme of the kingpin-type frame for the second estimation case is shown in Fig. 6.

The second estimation case simulates the formation of self-balanced lateral forces that bend the girders of a kingpin-type load-carrying system in their plane, as well as the torsion moments that twist the girders when climbing a high curb at an angle. It should be noted that the longitudinal force R_{kx} (Fig. 6), a part of the curb reaction, can be neglected due to its smallness.

The estimated lateral force is determined as a side reaction from the road covering on the verge of disrupting the adhesion of wheels when climbing a high curb at an angle [11]:

$$R_{kz}=\frac{1}{2}m_{nn}gf, \qquad (4)$$

where R_{kz} is the calculated lateral force that acts on the wheel of a semi-trailer, free from climbing the curb, N; τ_{nn} is the weight of a loaded semi-trailer, kg; g is the acceleration of free fall, m/s^2; f is the friction coefficient of the running surface of the pneumatic wheel against the road surface.

The estimated torsional moment that acts on the girder is determined as follows:

$$M_{kp}=R_{kz}H, \qquad (5)$$

where M_{kp} is the estimated torsional moment, N·m; *N* is the shoulder of lateral force relative to the longitudinal axis of the girder, m.

We record the functions of the bending and torsional moments under the characteristic modes of the frame and build the diagrams of the corresponding internal force factors (Fig. 7).

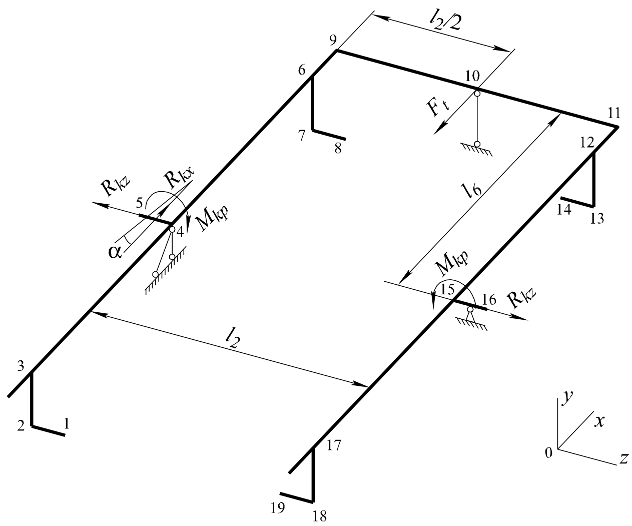

Fig. 6. Estimation scheme and the diagrams of bending and torsional moments for the second estimation case

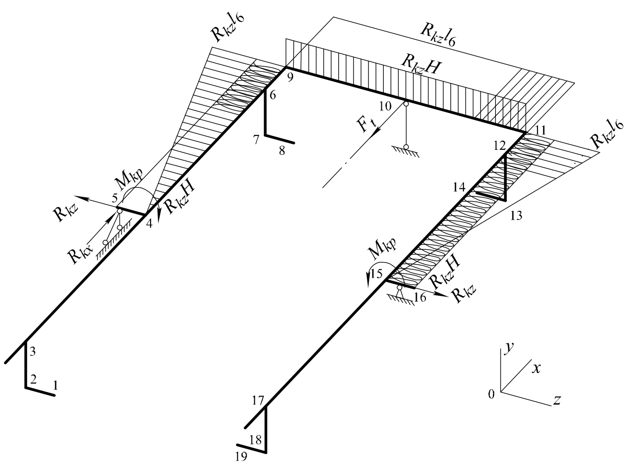

Fig. 7. Diagrams of bending and torsional moments for the second estimation case in the kingpin-type frame

The diagram of bending moments.

$$M_x(z)_{1-2}=0;\;\; M_x(y)_{2-3}=0;$$

$$M_z(x)_{3-4}=0;\;\; M_x(z)_{5-4}=0.$$

$$M_y(x)_{4-9}=R_{kz}x;\;\; x=0;$$

$$M_y=0;\;\; x=l_6;\;\; M_y=R_{kz}l_6.$$

$$M_y(z)_{9-11}=R_{kz}l_6;\;\; M_x(z)_{9-11}=R_{kz}H.$$

$$M_x(z)_{19-18}=0;\;\; M_x(y)_{18-17}=0;$$

$$M_z(x)_{17-15}=0;\;\; M_y(x)_{17-15}=0.$$

$$M_y(x)_{15-11}=R_{kz}x;\;\; x=0;\;\; M_y=0;\;\; x=l_6;\;\; M_y=R_{kz}l_6.$$

The diagram of torsional moments.

$$M_{kp}(z)_{1-2}=0;\;\; M_{kp}(y)_{2-3}=0;$$

$$M_{kp}(x)_{3-4}=0;\;\; M_{kp}(x)_{4-9}=R_{kz}H.$$

$$M_{kp}(z)_{19-18}=0;\;\; M_{kp}(y)_{18-17}=0;$$

$$M_{kp}(x)_{17-15}=0;\;\; M_{kp}(x)_{15-11}=R_{kz}H.$$

After obtaining the analytical expressions and building the diagrams of the bending and torsional moments for the second estimation case in a kingpin-type frame, we proceed to calculating the designed strength of girders.

As it follows from the diagrams of the bending and torsional moments (Fig. 7), the dangerous intersections for girders as regards the second estimation case are angular intersections 9, 11, where there is a complex stressed state.

In addition, at these intersections, one should take into consideration the torsional moment derived for the first estimation case, but with a dynamic coefficient equal to unity. We record the strength condition for these intersections using the third theory of strength [10]:

$$\sigma_{ekv}=\sqrt{\sigma^2+4\tau^2}=$$
$$=\sqrt{\left[\frac{M_y(9)_{4-9}}{W_y(9)}\right]^2+4\left[\frac{M_{kp}^{(1)}(9)_{4-9}+M_{kp}^{(2)}(9)_{4-9}}{W_{kp}(9)}\right]^2}\le[\sigma], \quad (6)$$

where $M_y(9)_{4-9}$ is the bending moment at intersection 9 of the girder's sections 4–9 for the second estimation case, N·m; $M_{kp}^{(1)}(9)_{4-9}$ is the torsional moment at intersection 9 of the girder's sections 4–9 for the first estimation case at $K_{\partial 1}=1$, N·m; $M_{kp}^{(2)}(9)_{4-9}$ is the torsional moment at intersection 9 of the girder's sections 4–9 for the second estimation case, N·m; $W_y(9)$ is the moment of resistance to bending at intersection 9(11) of the girder, m^3; $W_{kp}(9)$ is the moment of resistance to torsion at intersection 9(11) of the girder, m^3.

After disclosing the analytical expressions of the bending and torsional moments, as well as the geometric characteristics of dangerous intersections 9, 11 (Fig. 5), the strength condition (6) takes the following form:

$$\sigma_{ekv}=$$
$$=\sqrt{\left[\frac{\frac{1}{2}m_{nn}\,g\,f\,l_6}{\frac{\delta b^2}{3}\left(3\frac{h}{b}+1\right)}\right]^2+4\left[\frac{2\cdot\frac{1}{4}m_k g\left(l_4+l_5\right)+\frac{1}{2}m_{nn}\,g\,f\,H}{2(b-\delta)(h-\delta)\delta}\right]^2}\le[\sigma]. \quad (7)$$

Recall the same overall dimensions of the dangerous intersection *b, h*, similar to the preceding calculation, and determine the thickness of the walls δ based on the strength condition (7).

5. 3. Determining the strength condition for the estimation case: starting a tractor container carrier forward with an insurmountable obstacle in front of the wheels of the semi-trailer

The third estimation case is the calculation of the designed strength of the frame member when loading it in the longitudinal direction. The estimated scheme of the kingpin-type frame for the third estimation case is shown in Fig. 8.

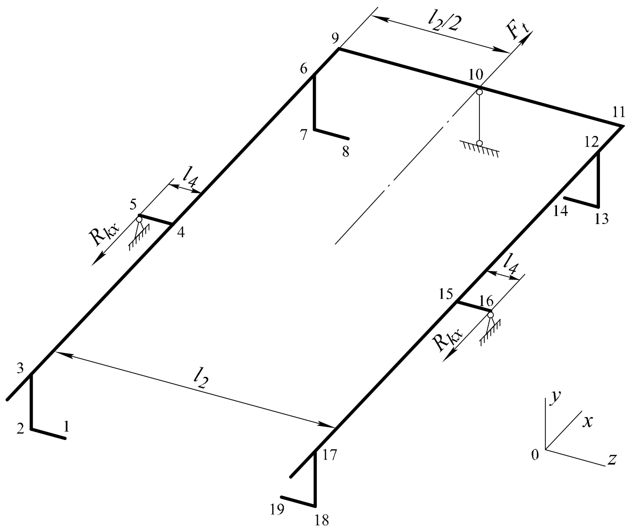

Fig. 8. Estimation scheme of the kingpin-type frame for the third estimation case

The third estimation case simulates the most severe load on the member of the kingpin-type frame in its plane. This estimation case is implemented at a traction effort on the verge of losing the adhesion of the tractor's drive wheels; the estimated traction effort is determined from the following formula [11]:

$$F_t = m_{tk} g f, \tag{8}$$

where F_t is the estimated traction effort of a tractor, N; m_{tk} is the weight of the tractor, which is concentrated on drive wheels, kg.

It follows from the estimated scheme of the semi-trailer that the system is symmetrical relative to the longitudinal axis; the reactions of the wheels are determined as follows:

$$R_{kx} = \frac{1}{2} F_t, \tag{9}$$

or, after fitting expression (8) to ratio (9):

$$R_{kx} = \frac{1}{2} m_{tk} g f. \tag{10}$$

Next, we record the functions of bending moments at the characteristic sections of the frame and build the appropriate diagram (Fig. 9).

$$M_y(z)_{5-4} = R_{kx} z; \quad z = 0; \quad M_y = 0;$$

$$z = l_{5-4} = l_4; \quad M_y = \frac{1}{2} m_{tk} g f l_4.$$

$$M_y(x)_{4-9} = R_{kx} l_4; \quad \frac{1}{2} m_{tk} g f l_4.$$

$$M_x(z)_{9-10} = R_{kx}(l_4 + z) = \frac{1}{2} m_{tk} g f (l_4 + z).$$

$$z = 0; \quad M_y = \frac{1}{2} m_{tk} g f l_4;$$

$$z = \frac{l_2}{2} = l_4; \quad M_y = \frac{1}{2} m_{tk} g f \left(l_4 + \frac{l_2}{2} \right).$$

$$M_y(z)_{16-15} = R_{kx} z; \quad z = 0;$$

$$M_y = 0; \quad z = l_{16-15} = l_4; \quad M_y = \frac{1}{2} m_{tk} g f l_4.$$

$$M_y(x)_{15-11} = R_{kx} l_4 = \frac{1}{2} m_{tk} g f l_4.$$

$$z = 0; \quad M_y = \frac{1}{2} m_{tk} g f l_4; \quad z = \frac{l_2}{2} = l_4;$$

$$M_y = \frac{1}{2} m_{tk} g f \left(l_4 + \frac{l_2}{2} \right).$$

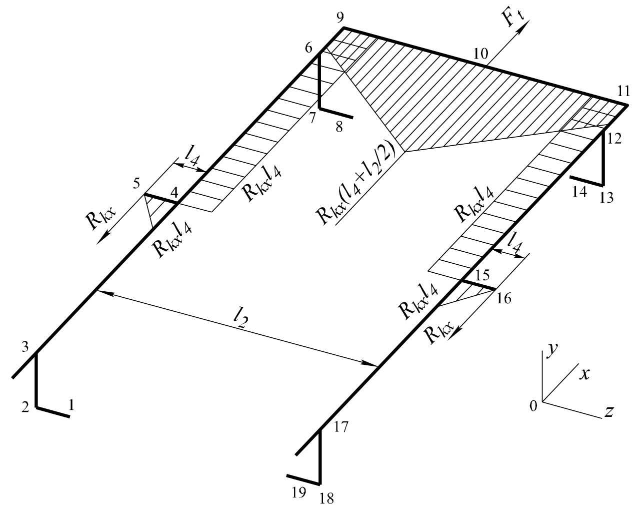

Fig. 9. Diagram of bending moments for the third estimation case in the kingpin-type frame

After obtaining the analytical expressions and building the diagram of bending moments for the third estimation case in the kingpin-type frame, proceed to calculating the designed strength of the frame member.

The diagram of bending moments (Fig. 9) shows that a dangerous intersection for the member of the kingpin-type frame for the third estimation case is intersection 10, where the bending moment in the plane of the frame is maximal. In addition, at this intersection, one should take into consideration the bending moment in the transverse plane, derived from the first estimation case, but with a dynamic coefficient equal to unity. In this case, there is a complex deflection with the strength condition recorded as follows [11]:

$$\sigma_z(10) = \frac{M_y^{(3)}(10)_{9-11}}{W_y(10)} + \frac{M_x^{(1)}(10)_{9-11}}{W_y(10)} \leq [\sigma], \tag{11}$$

where $\sigma_z(10)$ is the maximum total stress in a frame member, Pa; $M_y^{(3)}(10)_{9-11}$ is the bending moment at intersection 10 of the frame member for the third estimation case, N·m; $M_x^{(1)}(10)_{9-11}$ is the bending moment at intersection 10 of the frame member for the first estimation case at $K_{\partial 1} = 1$, N·m; $W_y(10)$ is the moment of resistance to bending of intersection 10 of the frame member relative to the y axis, m^3; $W_x(10)$ is the moment of resistance to bending of intersection 10 of the frame member relative to the x axis, m^3.

After disclosing the analytical expressions of bending moments, as well as the geometric characteristics of the cross section 10 (Fig. 5), the strength condition (11) takes the following form:

$$\sigma_z(10)=\frac{\frac{1}{2}m_{\text{tk}}gf\left(l_4+\frac{l_2}{2}\right)}{\frac{\delta b^2}{3}\left(3\frac{h}{b}+1\right)}+\frac{2\cdot\frac{1}{4}m_k gf\left(l_4+l_5\right)}{\frac{\delta h^2}{3}\left(3\frac{b}{h}+1\right)}\le[\sigma]. \quad (12)$$

We set the outer dimensions of intersection 10, *b, h,* already known from previous calculations; the rack thickness δ is determined from the strength condition (12).

Thus, given the overall thin-walled, rectangular, closed profiles of the force elements of the kingpin-type frame, selected for structural reasons, namely *b* and *h*, based on the strength conditions for three estimation cases of loading the carrying system, as well as their combinations, we obtain the appropriate thickness of racks of profiles δ. The reserve of strength accepts the greatest value of thickness δ.

Under the influence of lateral forces at turning, under the unsteady modes of movement caused by the skew-symmetric kinematic perturbations, the semi-trailer of an articulated tractor container carrier with elastic suspension experiences the rolls of static and dynamic origin, which can be fended off by a stabilizer bar.

The stabilizer bars of transverse stability in a static statement are calculated for ensuring a certain angular rigidity; under the dynamic criteria for choosing parameters for the stabilizer bars, the latter act as an additional elastic element of the dynamic system, which affects the natural dynamic characteristics of the system and thus the stability of the perturbed movement of such a system in the presence of the skew-symmetric kinematic perturbations.

However, in both cases, the key role belongs to the angular stiffness of the transverse stabilizer bar as an elastic element of the suspension of the semi-trailer for a tractor container carrier. For the case of a semi-trailer with a tractor container carrier with a kingpin-type frame, the geometric parameters of the transverse stabilizer bar are simplified; the estimation scheme is shown in Fig. 10.

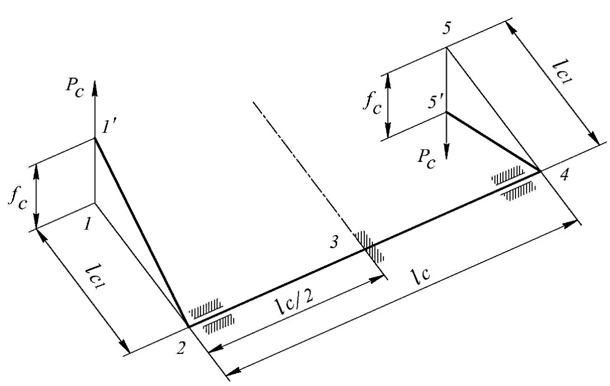

Fig. 10. Estimation scheme of the transverse stabilizer bar in a semitrailer of a tractor container carrier

The linear movement f_c of the transverse stabilizer bar is implemented by bending sections 1–2 and 5–4, as well as by twisting sections 2–4 (Fig. 10). The linear rigidity of the transverse stabilizer bar is determined as follows:

$$C_c=\frac{P_c}{f_c}, \quad (13)$$

where C_c is the linear rigidity of the transverse stabilizer bar, N/m; P_c is the load at roll, N; f_c is the linear movement of the transverse stabilizer bar, m.

For an arbitrary profile of the cross section of the transverse stabilizer bar:

$$C_c=\frac{E}{l_{c1}^2\left[\frac{l_{c1}}{3I_3}+(1+\upsilon)\frac{l_c}{I_p}\right]}, \quad (14)$$

where E is the elasticity module of the first kind of the material of the transverse stabilizer bar, Pa; I_3 is the axial moment of inertia of the cross-section of the transverse stabilizer bar, m^4; I_p is the polar moment of inertia of the cross-section of the transverse stabilizer bar, m^4; υ is the Poisson coefficient.

For the circular profile of the cross-section of the transverse stabilizer bar:

$$C_c=\frac{Ed^4}{20l_{c1}^2\left[\frac{l_{c1}}{3}+(1+\upsilon)\frac{l_c}{2}\right]}, \quad (15)$$

where d is the diameter of the rod that the transverse stabilizer bar is made of, m.

5. 4. The designation of the core stiffness of the stabilizer of the transverse stiffness of the profile of the large and round transverse overflow

The result of our study of the transverse stabilizer bar in a static statement is the established angular rigidity of the transverse stabilizer bar, which can be mathematically recorded in the form of the following formulae:

– for an arbitrary profile of the cross-section:

$$C_\beta=\frac{El_c^2}{2l_{c1}^2\left[\frac{l_{c1}}{3I_3}+(1+\upsilon)\frac{l_c}{I_p}\right]}; \quad (16)$$

– for a circular profile of the cross-section of the transverse stabilizer bar:

$$C_\beta=\frac{Ed^4l_c^2}{40l_{c1}^2\left[\frac{l_{c1}}{3}+(1+\upsilon)\frac{l_c}{2}\right]}. \quad (17)$$

6. Discussion of results of studying the methodology for calculating the designed strength of the kingpin-type load-carrying system in an articulated tractor container carrier

The established strength conditions for each estimation case is the result of a spatial study into the action of forces and torsional moments on the frame, which, in different situations, is regarded as a console girder or a hinged support. While driving over the irregularities of technological roads, the diagram is loaded, on one hand, with a bending moment, and, on the other hand, a torsional moment. The trailer part of the frame receives a load of uniform rupture action from the side of the tractor. The resulting condition of strength was determined taking into consideration the design of the frame girders, which have a square cross-section of the equilateral profile. The thickness of the profile of the walls according to the calculations depends on the external characteristics – the thickness and width, which, in most cases, are equivalent.

When climbing a high curb at an angle, the load is symmetrically distributed between the side girders, as one side part is largely loaded with a torsional moment and the other – a bending moment. The main load is received by a trailer part of the girder as it acts as a compensator for the actions of moments. Consequently, there is a need to use a girder with a non-equilateral profile; such a rank will be taken care of the showcase of significant moments.

When starting a tractor container carrier forward with an insurmountable obstacle in front of the wheels of the semi-trailer, the loads only act on rupture in all planes. This phenomenon necessitates additional recommendations for the use of girders with different external profiles.

The rigidity condition for the transverse stabilizer bar directly depends on the girder length given the condition of the empirical ratio of lengths to the intersections of girder profiles.

The sequential use of the devised techniques could make it possible to reduce the operational risks of frame ruptures and twisting at the design stage and shorten the time to calculate the strength of the kingpin-type carrier system of an articulated tractor container carrier.

The main limitation of this study is the need to use significant reserves of strength in calculations as our procedures do not take into consideration the simultaneous impact of two or more estimation cases.

Also, the work will look at the right dynamic options when transporting viscous, old and dynamically unstable vantages.

7. Conclusions

1. We have determined the strength conditions for each of the three estimation cases:

– movement over the irregularities of technological roads (3);

– climbing a high curb at an angle (7);

– starting a tractor container carrier forward with an insurmountable obstacle in front of the wheels of the semi-trailer (12).

2. The result of our research into the transverse stabilizer bars in a static statement is the determined angular stiffness of the transverse stabilizer bar, which can be mathematically recorded in the form of the following formulae:

– for an arbitrary profile of the cross section (16);

– for a circular profile of the cross section of the transverse stabilizer bar (17).

The use of estimation formulae (16) and (17) shortens the time for calculating the designed strength of the kingpin-type load-carrying system for an articulated tractor container carrier by 20–30 % compared to existing analytical calculation procedures. This reduction becomes possible due to the simultaneous use in the estimation formulae the resulting equations of torsional moments for the following cases:

– movement over the irregularities of technological roads;

– climbing a high curb at an angle;

– starting a tractor container carrier forward with an insurmountable obstacle.

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