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Mathematical Models of the Condition of the Suspension Wire of a New Spatial Rhombic Contact with a Flexible Retainer Taken Into Account of Temperature Changes

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Abstract: Taking temperature changes into account, the results of creating mathematical models for the states of new spatial rhombic contact suspension wires with flexible fixators will be applicable to all types of spatial rhombic contact suspension wires. It is assumed that all accumulated vertical and horizontal forces act at a single point in the middle of the span, influencing the supporting cables. The goal of creating the mathematical model for this situation is to pre-determine the failure, maintenance, and repair times of the new spatial rhombic contact suspension wires with flexible fixators, as well as to prevent accidents caused by external temperature effects.

Keywords: Spatial diamond-shaped catenary suspension, fixing rope, contact rope, elasticity, flexible retainer.

Introduction. According to its construction, in spatial rhombic contact suspension (SRCS) developed for artificial structures, contact wire (CW)s will have one or more robm-like appearance[.

In this case, the fixing rope (FR) are affected by the weight strength of their CW, the vertical loads accumulated at their connection points to the rope. Also, horizontal loadings are generated by the recursion of their CW in each rhombus, and interact with vertical loadings at homogeneous points. In addition, FR is also affected by loads distributed as a result of its own weight force.

In artificial structures with a small (up to 25 meters) freezing range, FR is affected by the accumulated forces of CW at one point.

To generate computational methods and equations that are appropriate for all types of SRCS, we introduce the following restriction: all accumulated vertical and horizontal forces acting on FRs are affected at a single point between the interval.

Such a scheme is only fully suitable for SRCS with single Rhombus CW in the range, but differs from the position of forces in the suspension with multiple Rhombus CW in the range. But this situation is only researched to determine the change in the voltage of FRs from the change in ambient temperature. Consequently, the points of application of forces from the loadings generated by CW to FR do not cause a decrease in accuracy when calculating the dependence of Osma FR drag on ambient temperature. Also, in the solidification range, geometric parameters of the FR location, that is, vertical and horizontal projections of the hanging of the ROPEs at different points in the range, are determined.

We determine the relationship between the tensile forces of FRs between the solidification in two different (temperature changes and it does not change) computational modes. Let's consider the operation of the suspension between the suspension points of FRs at the same height level and at the same distance from the road axis.

When the length of FR is not hanging in the hardening range, when the hanging is viewed as a non-existent thread, one defines its length by the geometric sum of the projections along the axes as:

$$L = 2\sqrt{\left(\frac{l}{2}\right)^2 + a^2 + h^2}\,. \qquad (1)$$

Taking into account the hanging of FR (Figure 1), we define its length in the solidification range to be similar to the approximate equation of the length of a wire that hangs freely in the range, but taking into account its spatial state as follows:

$$L = l + \frac{8(a^2+h^2)}{2l}\,. \qquad (2)$$

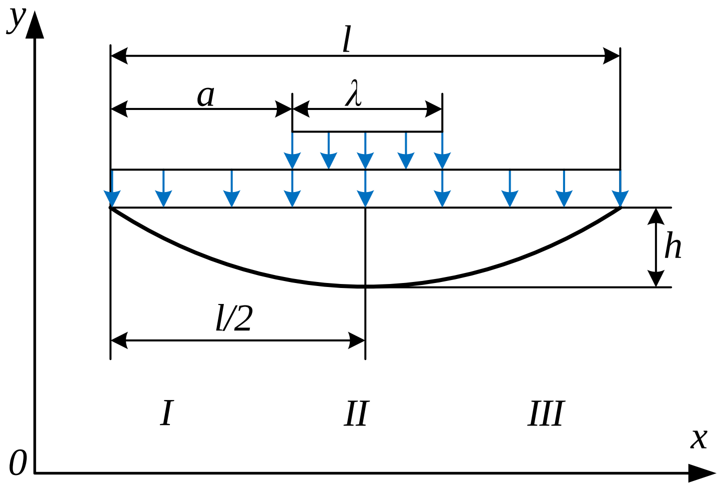

Figure 1. Projection of the SRCS on the x0y plane: I, II, III – beginning, middle (maximum) and ending parts of the wire suspension, respectively

To determine the length of the wire in the winding range, we rely on the assumption that it is an absolutely flexible thread, that is, the bending stiffness of the wire is not taken into account. In this case, the equation makes it possible to approximate the length of the wire in the range. But to obtain the equation of state, it is important to know the change in the value of under the influence of external factors. When determining the wire length change in the compression interval based on (1), the degree of accuracy is determined using an expression equivalent to this equation.

The relationship between the temperature and load changes and the wire lengths in the range is determined using the following expression:

$$L_x = L_1\left[1 + \alpha_t(t_x - t_1) + \frac{T_x - T_1}{ES}\right], \qquad (3)$$

where: L_1, T_1 - the length and tensile strength of the FR at the initial temperature(t_1)in the corresponding Raish; T_x – the tensile strength of the FR at the change in temperature t_x; α_t - the coeficient of the change in the temperature effect of the FR length.

When calculating vertical hangers, it is also taken as $L \approx l$ to determine the length of the wire, taking into account the theory that the length of the wire is slightly different from the length of the range. Because

$$L = l\sqrt{1+\frac{a^2+h^2}{\left(\frac{l}{2}\right)^2}}. \qquad (4)$$

due to the fact that the value of the term $\frac{a^2+h^2}{\left(l/_2\right)^2}$ in the equation is very small at one, it can be written as follows:

$$L = l\left[1+\frac{1}{2}\cdot\frac{a^2+h^2}{\left(\frac{l}{2}\right)^2}\right]. \qquad (5)$$

Then

$$L_1 = l\left[1+\frac{1}{2}\cdot\frac{a_1^2+h_1^2}{\left(\frac{l}{2}\right)^2}\right], \quad \text{and} \quad L_x = l\left[1+\frac{1}{2}\cdot\frac{a_x^2+h_x^2}{\left(\frac{l}{2}\right)^2}\right]. \qquad (6)$$

and by putting the values L_1 and $L_x$in the (3) equation, we define t_x from it the following expression of:

$$t_x = \frac{2(a_x^2+h_x^2-a_1^2-h_1^2)}{\alpha_t[l^2+2(a_1^2+h_1^2)]}+t_1-\frac{T_x-T_1}{\alpha_t ES} = M_x+t_1-\frac{T_x-T_1}{\alpha_t ES}, \qquad (7)$$

here $M_x = \frac{2(a_x^2+h_x^2-a_1^2-h_1^2)}{\alpha_t[l^2+2(a_1^2+h_1^2)]}$.

We substitute the values of the generated a, h for the suspension in which there are rhombic contact wires in the range and for M_x we will have the following expression:

$$M_x = \frac{2B^2\left[\left(\frac{n^2K}{T_x+n^2K}\right)^2-\left(\frac{n^2K}{T_1+n^2K}\right)^2\right]+\frac{(g_{\text{T}}+g_{\text{K}})^2l^4}{8}\left(\frac{1}{T_x^2}-\frac{1}{T_1^2}\right)}{\alpha_t\left[l^2+2B^2\frac{n^2K}{T_1+n^2K}+\frac{(g_{\text{T}}+g_{\text{K}})^2l^4}{8}\right]}. \qquad (8)$$

putting the value M_x (7) in the equation of state, we obtain its following expression:

$$t_x = \frac{2B^2\left[\left(\frac{n^2K}{T_x+n^2K}\right)^2-\left(\frac{n^2K}{T_1+n^2K}\right)^2\right]+\frac{(g_{\text{T}}+g_{\text{K}})^2l^4}{8}\left(\frac{1}{T_x^2}-\frac{1}{T_1^2}\right)}{\alpha_t\left[l^2+2B^2\frac{n^2K}{T_1+n^2K}+\frac{(g_{\text{T}}+g_{\text{K}})^2l^4}{8}\right]}+t_1-\frac{T_x-T_1}{\alpha_t ES}. \qquad (9)$$

The induced (9) equation of state is general, and any number of rhombuses in the range CW allows calculating the drag on the FRs of SRCS.

It is assumed that the value of SRCS , whose CW are one Rhombus in the Fusion range, n is equal to one.

To determine the B parameter, it will be necessary to set the maximum value of C, which must correspond to the permissible value T_{pyx} of the pull of FRs [3].

The values of corresponding C to the condition $T_x < T_{\text{pyx}}$ will be less than the value C of the received at T_{pyx}. The value of C in T_{pyx} is selected for hangings in artificial structures based on the exact dimensions of the tunnel. The maximum value of the deviation of CW from the road axis is equal to a $C = 0{,}5$ meter according to the existing norms [3].

The permissible deviation from the CW larnying Road axis at the hardening points in the tunnels is due to the absence of wind impact on the suspension in artificial structures, the maximum value of this size is obtained according to existing standards.

We have determined the parameter a for the length of the interval calculated at T_{pyx}. Now we will be able to determine the value $B = a + C$.

The value of B assesses the horizontal size of the hanger. In addition, when T_{pyx} changing, the values of a and C change accordingly, but in this case their sum, that is, the value of B, remains unchanged.

If the value of the B obtained as a result of the calculations is larger, taking into account the length of the fixing element, it will be possible to replace it with FRs of more permissible strength, taking into account the conditions of artificial structures, or it will be necessary to reduce the length of the freezing interval of the suspension.

If the temperature changes in artificial structures and tunnels are significantly less than in open air, then a situation may arise in which a certain value of C must correspond to a certain temperature. Most often, these parameters can be set for the average temperature. To determine the values C and a, it will be necessary to know the pull of FRs corresponding to this temperature.

When installing SRCS on curved paths, it is impossible to build without taking into account the C and a values.

At a temperature of t_x, it will be necessary to determine the value of a, choosing the desired value C. In this case, we will use the specified value T_1. once we have determined the values of C and a, the dependence equation of State $T_x = f(t_x)$ is constructed. If , determined by the obtained correlation, the values of $T_{\text{ўр}}$, T_1 differ from their approximate values, then the exact calculation is carried out in the same order. But the chosen value of C must correspond to the value $T_{\text{ўр}}$ found for the curved path. If the average tensile strength value $T_x = f(t_x)$ obtained from the defined curve is hardly different from that found in the first case, then further clarifications are not required afterwards. Thus, we can determine the parameters of the known C and a the ones at any temperature and for the corresponding pull of the FRs.

When calculating hangers for limited conditions, it is important to know not only the geometric parameters of the hanger FR wires, but also the limits of their change in the entire range of ambient temperature. It is also important to know the limits of variation in SRCS FRdrag.

Changes in the ambient air temperature lead to changes in the drag of the suspension CW and, as a result, to a change in their altitude status. But given that temperature changes in tunnel sections occur at much smaller limits than in open air, changes in parameters do not lead to a deterioration in the flow transition from the suspension to the TQ.

Consider the change in the state of CW in a new SRCS with a flexible fixator when the ambient temperature changes, i.e. the change in the tension of CW firmly fixed to the fixators..

Changes in wire length caused by temperature and deformations in the compression interval (2) are determined using the expression. In the compression range, the length of the wire L is determined by the axis of suspension and the tension of the wire. It can be identified by the following expression:

$$L = 2M + \frac{g_k^2 (2M)^2}{24K^2} = 2M\left[1 + \frac{g_k^2 M^2}{6K^2}\right]. \qquad (10)$$

The projection of the wire M in the horizontal plane is determined by the geometric sum of its Y, Z dimensions on its axes (Figure 1) and has the following appearance:

$$M = \sqrt{\left(\frac{l}{2}\right)^2 + C^2} = \frac{l}{2}\sqrt{1 + \frac{C^2}{(l/2)^2}}. \qquad (11)$$

If one considers that the value of $\frac{C^2}{(l/2)^2}$ is too small at once, then the expression (11) can be written with sufficient degree of accuracy as:

$$M = \frac{l}{2}\left[1 + \frac{l}{2} \cdot \frac{C^2}{(l/2)^2}\right]. \qquad (12)$$

The hanging of the wire (1) is taken into account in the expression. This equation is expressed as follows for two different states of the string:

$$L_1 = 2\frac{l}{2}\left[1+\frac{1}{2}\cdot\frac{C_1^2}{(l/2)^2}\right]\left[1+\frac{\left(\frac{l}{2}+\frac{C_1^2}{l}\right)^2\cdot g_k^2}{6K_1^2}\right]. \quad (13)$$

and

$$L_2 = 2\frac{l}{2}\left[1+\frac{1}{2}\cdot\frac{C_2^2}{(l/2)^2}\right]\left[1+\frac{\left(\frac{l}{2}+\frac{C_2^2}{l}\right)^2\cdot g_k^2}{6K_2^2}\right]. \quad (14)$$

Putting (13) and (14) in (10), we derive the following equation:

$$\left[1+\frac{1}{2}\cdot\frac{C_2^2}{(l/2)^2}\right]\left[1+\frac{\left(\frac{l}{2}+\frac{C_2^2}{l}\right)^2\cdot g_k^2}{6K_2^2}\right] = \left[1+\frac{1}{2}\cdot\frac{C_1^2}{(l/2)^2}\right]\cdot$$

$$\cdot\left[1+\frac{\left(\frac{l}{2}+\frac{C_1^2}{l}\right)^2\cdot g_k^2}{6K_1^2}\right]\cdot\left[1+\alpha_t(t_2-t_1)+\frac{K_2-K_1}{ES}\right]. \quad (15)$$

By making the corresponding changes and discarding two small amounts of organizers, we obtain:

$$\frac{\left(\frac{l}{2}\right)^2\cdot g_k^2}{6K_2^2}+\frac{1}{2}\cdot\frac{C_2^2}{\left(\frac{l}{2}\right)^2} = \frac{\left(\frac{l}{2}\right)^2\cdot g_k^2}{6K_1^2}+\frac{1}{2}\cdot\frac{C_1^2}{\left(\frac{l}{2}\right)^2}+\alpha_t(t_2-t_1)+\frac{K_x-K_1}{ES}. \quad (16)$$

or

$$K_2-\frac{l^2 g_k^2 ES}{24K_2^2}-\frac{2C_2^2 ES}{l^2} = K_1-\frac{l^2 g_k^2 ES}{24K_1^2}-\frac{2C_1^2 ES}{l^2}-\alpha_t ES(t_2-t_1). \quad (17)$$

When generating the last equation, the tension K_2 depends not only on the temperature, but also on theC_2. Therefore, it will be necessary to know the dependence $K = f(C)$ to replace in with the resulting C_2 equation of state.

To determine this relationship, consider the following expression obtained in [3]:

$$N = \frac{4KC}{l}. \quad (18)$$

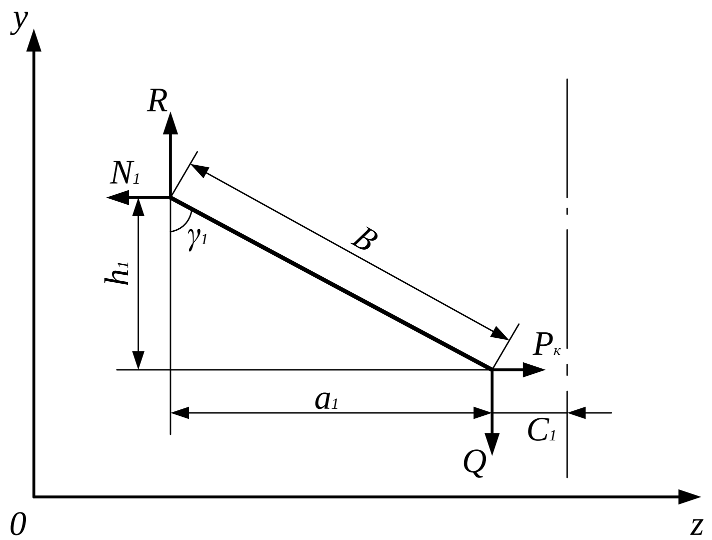

Figure 2. Calculation scheme for determining the available forces in the YOZ plane

We define the length of the flexible fixator by the following equation:

According to figure 2, we define the following:

$$a = bsin\gamma \frac{b}{\sqrt{1+ctg^2\gamma}} \quad (19)$$

$$ctg\gamma = \frac{Q}{N} \quad (20)$$

Putting (18) and (20) in (19), we obtain:

$$a = \frac{b}{\sqrt{1+\frac{Q^2l^2}{16K^2C^2}}}. \quad (21)$$

It is known [4], $B - C = \frac{b}{\sqrt{1+\frac{Q^2l^2}{16K^2C^2}}}$. From this:

$$1 + \frac{Q^2l^2}{16K^2C^2} = \left(\frac{b}{B-C}\right)^2, \quad (22)$$

here according to figure 2 $B = bsin\gamma + C$.

(22) we give the following view:

$$\frac{Q^2l^2}{16K^2C^2} = \left(\frac{b}{B-C}\right)^2 - 1. \quad (23)$$

From this:

$$K = \frac{Ql}{4C\sqrt{\left(\frac{b}{B-C}\right)^2 - 1}}. \quad (24)$$

To calculate the value K of the resulting expression for any value C and to for the entire expected range of possible changes makes it possible to form a dependency graph of $K = f(C)$.

To make the calculations, let's make (9) look like this:

$$t_x = \left[\frac{K_1}{\alpha_t ES} - \frac{l^2 g_k^2}{24\alpha_t K_1^2} + t_1 - \frac{2C_1^2}{\alpha_t l^2}\right] - \frac{K_2}{\alpha_t ES} + \frac{l^2 g_k^2}{24\alpha_t K_2^2} + \frac{2C_2^2}{\alpha_t l^2}. \quad (25)$$

The drag of a new SRCS CW with a flexible fixator is calculated in the following order:

1) the parameters B, C of the suspension are selected. It is also assumed that the value $K_{\text{мах}}$ for the tunnel suspension is equal to 500 mm;
2) the dependence $K = f(C)$ is constructed for the entire range of expected variations of K;
3) using the equation of State $K_x = f(t_x)$, a relation is constructed and the equation is solved by the substitution method. by replacing the next value C from the graph $K = f(C)$, the corresponding value of is determined and exchanged for the state equation. The temperature value for the accepted value of .

Thus, continuing to replace each value of C, we determine the setting curve, assuming that the computational regime of the minimum temperature is known.

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