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RESEARCH ARTICLE

DETERMINATION OF THE STRESS-STRAIN STATE OF THE FILAMENT YARN

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ABSTRACT

The solution that is obtained using the equation of the curved axis is in the form of an infinite series and practical application is associated with great mathematical difficulties. In addition, the differential equation of the curved axis is obtained for pure bending, i.e. The rod is bent due to the moments acting in the longitudinal sections, and there are no lateral forces. A bending of a flexible thread occurs under the influence of its own weight, which in many cases is directed precisely in the transverse direction of the rod or has a component directed perpendicular to the axis of the flexible thread. All this circumstance makes it necessary to create a new method for calculating the strength and rigidity of flexible threads. In the present paper, for the first time, this problem is considered not in Eulerian a but in Lagrangian variables. in variables not connected with a deformed body, but with an undeformed body. Exact analytical solutions are obtained, and after obtaining the solution in Lagrangian variables it is possible to go over to Euler variables. Moreover, the exact analytical solution obtained is much simpler than existing solutions and the application in practice presents no difficulties.

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INTRODUCTION

A flexible thread means a body whose one size is much larger than the other two sizes and does not resist bending. Widely used ropes, chains, cables, electric wires, cables, etc. can be considered as flexible threads. Even pipeline stacked at great depth can be considered as a flexible thread. It is known that when a flexible thread is considered inextensible, under the influence of its own weight it takes the form of a chain line. When calculating for strength, one must take into account the elongation of the flexible thread. In all existing studies, to perform strength calculations is used the differential equation of the curved axis of the filament. The solution that is obtained using the equation of the curved axis is in the form of an infinite series and practical application is associated with great mathematical difficulties In addition, the differential equation of the curved axis is obtained for pure bending, i.e. The rod is bent due to the moments acting in the longitudinal sections, and there are no lateral forces. A bending of a flexible thread occurs under the influence of its own weight, which in many cases is directed precisely in the transverse direction of the rod or has a component directed perpendicular to the axis of the flexible thread.

All this circumstance makes it necessary to create a new method for calculating the strength and rigidity of flexible threads. In the present paper, for the first time, this problem is considered not in Eulerian a but in Lagrangian variables. in variables not connected with a deformed body, but with an undeformed body. Exact analytical solutions are obtained, and after obtaining the solution in Lagrangian variables it is possible to go over to Euler variables. Moreover, the exact analytical solution obtained is much simpler than existing solutions and the application in practice presents no difficulties.

The equilibrium equation of flexible threads

To obtain the equilibrium equation of a flexible thread, let us consider the equilibrium of an arbitrary element ds. Per element ds force acts -$\overline{T}$ and $\overline{T}+d\overline{T}$ The applied at the ends of it and the external force $\overline{F}ds$. TorThen the equation of equilibrium will have the form [2]:

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$$\overline{F}ds+\left(-\overline{T}\right)+\overline{T}+d\overline{T}=0$$

from this equation

$$\overline{F}+\frac{d\overline{T}}{ds}=0 \qquad \text{……………………………………….(1)}$$

Equation (1) is the equilibrium equation of the filament in vector form. We project this equation on the axes of the Cartesian coordinate system $O\,\xi\eta\xi$ .The projections of the tension force ***T*** will be

$$T_\xi=T\frac{d\xi}{ds};T_\eta=T\frac{d\eta}{ds};T_\xi=T\frac{d\xi}{ds}$$

Then equation (1) in the projections will be

$$\left\{\frac{d}{ds}\left(T\frac{d\xi}{ds}\right)+F_\xi=0;\frac{d}{ds}\left(T\frac{d\eta}{ds}\right)+F_\eta=0;\frac{d}{ds}\left(T\frac{d\xi}{ds}\right)+F_\xi=0\right. \qquad \text{…………………………………….(2)}$$

Determination of the tension force of the filament under the influence of gravity and transverse currents

Formulation of the problem: It is believed that, the thread attached to the two ends, is a force of gravity and force crossflow.The coordinate system is chosen so that the beginning of the system coincides with the lower point of the thread. The x axis is directed horizontally, perpendicular to the direction of the transverse flow, the y axis is directed along the stream, the z axis, is perpendicular to the *xoy*plane.It is believed that prior to deformation, the thread was positioned along the axis *x*. Then the point with coordinates (*x,0,0*) before deformation, it takes the position with coordinates (ξ,η,ξ)after deformation. Components of the displacement vector $\overline{u}(x)$points (*x,0,0*) along the axis *x,y,z*will be denoted by $u(x),v(x),w(x)$. Then the connections between the coordinates of the point after deformation (Euler variables) and before deformation (Lagrange variables) have the form:

$$\{\xi=x+u(x);\eta=v(x);\xi=w(x)$$

…………………………………(3)

For the case under consideration, equations (2) will be:

$$\left\{\frac{d}{ds}\left(T\frac{d\xi}{ds}\right)=0;\frac{d}{ds}\left(T\frac{d\eta}{ds}\right)=q;\frac{d}{ds}\left(T\frac{d\xi}{ds}\right)=g\right. \qquad \text{………………………………….(4)}$$

Where $q-$unit length weight, $g-$the force of the transverse flow per unit lengthIf the length of the element dsbefore deformation, we denote by dx and the values q and g before deformation through $q_0$and $g_0$then

$$qds=q_0dx;\ gds=g_0dx$$

Of(4)

$$\left\{d\left(T\frac{d\xi}{ds}\right)=0;d\left(T\frac{d\eta}{ds}\right)=q_0dx;d\left(T\frac{d\xi}{ds}\right)=g_0dx\right. \qquad \text{……………………………………...(5)}$$

Integrating (5), we have:

$$\left\{T\frac{d\xi}{ds}=H;T\frac{d\eta}{ds}=q_0x+C_2;T\frac{d\xi}{ds}=g_0x+C_3\right. \qquad \text{……………………………………….(6)}$$

Where$H,C_2,C_3-$are integration constants.Of (3)

$$ds=\sqrt{(d\xi)^2+(d\eta)^2+(d\xi)^2}=\sqrt{(1+u)^2+v^2+wdx}$$

When for $\frac{d\xi}{ds}, \frac{d\eta}{ds}, \frac{d\xi}{ds}$ entering into (6) we obtain.:

$$\begin{cases} \frac{d\xi}{ds} = \frac{1+u}{\sqrt{(1+u)^2 + v^2 + wdx}}; \frac{d\eta}{ds} = \frac{v}{\sqrt{(1+u)^2 + v^2 + wdx}}; \frac{d\xi}{ds} = \frac{w}{\sqrt{(1+u)^2 + v^2 + wdx}} \end{cases} \quad \text{……………………………(7)}$$

When. $x = 0; \frac{d\eta}{ds} = 0; \frac{d\xi}{ds} = 0$ This means that in (6) $C_2 = C_3 = 0$ Consequently

$$\begin{cases} T\frac{1+u}{\sqrt{(1+u)^2 + v^2 + wdx}} = H \ ; T\frac{v}{\sqrt{(1+u)^2 + v^2 + wdx}} = q_0 x; T\frac{w}{\sqrt{(1+u)^2 + v^2 + wdx}} = g_0 x \end{cases} \quad \text{……………………………(8)}$$

whence

$$T = \sqrt{H^2 + (q_0^2 + g_0^2)x^2} \quad \text{……………………………(9)}$$

As seen from (9), the tension force gets its maximum value for large values in absolute value x .The strength condition for this case will be

$$T \le \sigma_T \quad \text{…………………………..(10)}$$

Where σ_T – yield strength .Taking into account (10) in (9) for the maximum value*x*, we obtain

$$x_{\max} = \sqrt{\frac{\sigma_T^2 - H^2}{q_0^2 + g_0^2}} \quad \text{…………………………..(11)}$$

Determination of displacements

Elongation of the thread [3]

$$\varepsilon_x = \frac{ds - dx}{dx} \quad \text{…………………………..(12)}$$

Of(3)

$$ds = \sqrt{(1+u')^2 + v'^2 + w'^2}\,dx$$

When of (12)

$$\varepsilon_x = \sqrt{(1+u')^2 + v'^2 + w'^2} - 1 \quad \text{…………………………..(13)}$$

Dividing both sides of the second and third equations of system (8) by the corresponding sides of the first equation of the same system, we obtain:

$$v' = \frac{q_0}{H}x(1+u'); \quad w' = \frac{g_0}{H}(1+u') \quad \text{……………………………(14)}$$

Substituting (14) into (13) we have:

$$\varepsilon_x = (1+u')\sqrt{1 + \frac{x^2}{a^2}} - 1 \quad \text{………………………………(15)}$$

Where

$$a^2 = \frac{H^2}{q_0^2 + g_0^2} \quad \text{………………………………(16)}$$

If the deformations are elastic, then

$$T = E\varepsilon_x \quad \text{……………………………..(17)}$$

Where E - product of the Young's modulus on the cross-sectional area of the filament. Substituting (9) and (15) into (17), we obtain

$$1 + u' = \frac{a}{\sqrt{a^2 + x^2}} + \frac{H}{E}$$

……………………………………….(18)

If we integrate (18) with the condition $x + u(x) = \xi = 0$, when $x = 0$ we obtain:

$$x + u(x) = \frac{H}{E}x + a\ln\left(\frac{x}{a} + \sqrt{1 + \frac{x^2}{a^2}}\right) \quad \text{……………………………………….(19)}$$

Taking into account (18) in the first equation (14), we obtain:

$$v' = \frac{q_0}{E}x + b\frac{x}{\sqrt{a^2 + x^2}} \quad \text{……………………………………….(20)}$$

Where

$$b = \frac{q_0}{\sqrt{q_0^2 + g_0^2}} \quad \text{………………………………………..(21)}$$

If we integrate (20) with the condition $v=0$ when $x = 0$ we obtain:

$$v = \frac{q_0}{2E}x^2 + b\left(\sqrt{a^2 + x^2} - a\right) \quad \text{………………………………………..(22)}$$

In a similar way w, we get:

$$w = \frac{q_0}{2E}x^2 + k\left(\sqrt{a^2 + x^2} - a\right) \quad \text{………………………………………….(23)}$$

Where

$$k = \frac{g_0}{\sqrt{q_0^2 + g_0^2}} = \sqrt{1 - b^2} \quad \text{………………………………………….(24)}$$

If the thread is inextensible, i. e. $E = \infty$, we get

$$\begin{cases} x + u(x) = \xi = a\ln\left(\frac{x}{a} + \sqrt{1 + \frac{x^2}{a^2}}\right) \\ v(x) = \eta = b\left(\sqrt{a^2 + x^2} - a\right) \\ w(x) = \varsigma = k\left(\sqrt{a^2 + x^2} - a\right) \end{cases} \quad \text{………………………………………….(25)}$$

Of (25) we get:

$$\eta = ab\left(ch\frac{\xi}{a} - 1\right); \quad \xi = ak\left(ch\frac{\xi}{a} - 1\right) \quad \text{………………………………………….(26)}$$

As can be seen from (26), when the thread is inextensible in both planes, i.e. in the planes $\xi o \eta$ and $\zeta o \eta$ the equation of the chain line is obtained.

In the particular case when there is no transverse flow $g_0 = 0; \quad w = 0$ и (26) obtains the form:

$$\eta = ab\left(ch\frac{\xi}{a} - 1 \right); \quad \xi = 0$$

Thus, the particular case of the general solution obtained coincides completely with the known particular solution.

Results

- Equilibrium equations of a flexible thread in the Lagrange variables are derived.
- Is found the analytical expression for the normal stress depending on the length of the sagging section, the linear weight and the intensity of the transverse currents.
- Is determined. the critical length of the sagging section from the tensile strength condition.
- Is foundan analytical expression for displacements in the horizontal and vertical directions.
- It is proved that when the filament is inextensible, it has the form of a chain line.

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