Fig. 5. Electron micrograph of a sample of untreated vermiculite of fired T = 400° C.

As shown by electron microscopic studies of untreated vermiculite calcined at T = 400° C, its full swelling is not observed. And when processing with reagents (the most successful samples were chosen after physico-chemical studies), the similarity of the samples obtained is evident, namely, the unprocessed samples burned at 900° C have the same form as those treated at 400° C with reagents.

Proceeding from the studies of electron microscopy, we see that samples of raw vermiculite burned traditionally and samples treated with chemical solutions (baked at 400° C) have a similar structure.

On the basis of the application of physical and chemical analysis methods it is necessary to conclude that the most effective is the treatment of vermiculite with chemical solutions and **baking** at 400° C. Similar features of vermiculite, peculiar to phlogopite, allow to consider a sample, preliminarily held in a chemical solution and fired to 400 C, which is the most acceptable for technological parameters and operational requirements for use in the construction industry.

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THE STRESS-STRAIN STATE OF THE FLAT ROPE OF HOISTING ENGINE WITH CONSIDERING THEIR TECHNICAL STATE

I. Belmas, Dr. of Technical science, Full Prof.
Dniprovsk State Technical University, Ukraine
D. Kolosov, Dr. of Technical science, Associate Prof.
O. Dolgov, Cand. of Technical science, Associate Prof.
State Higher Educational Institution "National Mining University", Ukraine
G. Tantsura, Cand. of Technical science, Associate Prof.
Dniprovsk State Technical University, Ukraine

Conference participants

Obtained an analytical dependence for determining the tensile forces acting in cables of the flat rubberized rope. It takes into account the design of the hoisting engine – the deviations of generating line of the drum from a straight and of the possible break of the cable in rope. A comprehensive account of the impact of various factors on the stress-strain state of the rope allows determining the loss of tractive capacity in operation on the hoisting engine. The results should be taken into account in the design and operation of hoisting and transporting machines with flat traction bodies.

Keywords: *hoisting engine drum, geometrical parameters, flat rubberized rope, breaks of tractive elements, complete the impact of various factors, stress-strain state, and analytical dependences.*

Introduction. Flat rubberized ropes are widely used as traction units of lifting and transporting machines. The design, technical condition of the machine and the conditions of operation affect the stress-strain state of their tractive elements, including the ruptures of the cables. In the process of the rope motion with a damaged cable, the field of stress caused by various factors may superpose and affect the actual ultimate strength of the rope.

State of question and formulation of the problem study. Methods for studying the influence of a complex of factors on the stress-strain state of the rubberized rope are absent. A development for this method is a ***topical scientific and technical task***. Its solution will determine the loss of traction capacity of the rope, caused by the construction of the hoisting machine and the possible destruction of one of its cables.

Influence of ruptures of cables in rubberized ropes on the distribution of forces in their width for different conditions was investigated in many papers [1-7]. They did not consider a problem of the combined effect of several factors.

Main content of the work. The tractive elements operate within the framework of the linear Hooke law. This allows the task to be divided into two problems - determining the stress-strain state of the rope under the influence of external factors (before the damage to the rope) and determining the impact of the tractive elements breaks. The results should be composed.

In the second problem, to the edges of the cable, caused by its rupture, apply forces equal and opposite to those acting in it before the rupture. The destruction of the cable locally changes the design of the rope. At the section of the cable destruction, their number in the rope decreases. Keep the conformity of the design of the rope before and after the damage. For this purpose, by the orthogonal section through the place the break, divide the rope into two segments. Define the conditions for compatibility of deformation of the segments. Assume the boundary conditions identical to those in the first problem. Consider the application of the algorithm on an example of determining the stress-strain state of a flat rope with a ruptured cable on a convex drum of a hoisting-transport machine.

The rope of the hoist has a considerable length and interacts with the convex drum. The subscript of this part of the rope is 2. Adjacent parts, respectively, have subscripts 1 and 3. Let's assume that the drum is in the shape of a parabola. Average length of rope is *L*.

On the drum, the strains of cables, due to changes of their shape, are determined by dependencies:

$$\varepsilon_i = 2\left(\frac{R_{max} - \left(R_{max} - R_{min}\right)\left(\frac{i}{M}\right)^2}{R_{max} - R_{min}}\right), \tag{1}$$

where R_{min}, R_{max} – respectively, the minimum and maximum radii of cables on the drum; *i* – the cable number; *M* – the cables quantity.

Mean length of cables is

$$X = \frac{R_{max} + R_{min}}{2}\alpha,$$

where α – angle of contact with the drum.

Consider the *x*-axis, which is directed along the rope. Coefficients of the desired quantities will have the respective subscripts. To them we will include the numbers of the segments to which they relate, and the cables numbers (*i*). The boundary conditions:

$$\begin{aligned} &x \to -\infty \quad u_{1,i} = 0, \quad p_{1,1} = p_{1,2} = \ldots = p_{1,N}, \\ &x \to \infty \quad u_{3,1} = u_{3,2} = \ldots = u_{3,N}, \quad p_{3,i} = P, \end{aligned} \tag{2}$$

where *P* – the value of the force applied to the rope assigned to the number of cables.

Conditions of compatibility of deformation of the rope sections:

$$\begin{aligned} &x = 0 \quad u_{1,i} = u_{2,i}, \quad p_{1,i} = p_{2,i}, \\ &x = L \quad u_{2,i} = u_{3,i}, \quad p_{2,i} = p_{3,i}. \end{aligned} \tag{3}$$

In the above dependencies and further, in the lower subscript, the first digits correspond to the segments number. Consider the deformation of the rubberized rope, the boundary conditions and conditions of compatibility. We will get the solution of the first problem:

$$u_{1,i} = \sum_{m=1}^{M} A_{1,m} e^{\beta_m x} \cos\left(\mu_m \left(i - 0,5\right)\right) + \frac{Px}{EF}, \tag{4}$$

$$p_{1,i} = EF \sum_{m=1}^{M-1} A_{1,m} e^{\beta_m x} \beta_m \cos\left(\mu_m \left(i - 0,5\right)\right) + P, \tag{5}$$

$$u_{2,i} = \sum_{m=1}^{M-1} \left(A_{2,m} e^{\beta_m x} + B_{2,m} e^{-\beta_m x}\right) \cos\left(\mu_m \left(i - 0,5\right)\right) + \frac{P}{EF} x, \tag{6}$$

$$p_{2,i} = EF \sum_{m=1}^{M-1} \left[\left(A_{2,m} e^{\beta_m x} - B_{2,m} e^{-\beta_m x}\right) \beta_m + D_m\right] \cos\left(\mu_m \left(i - 0,5\right)\right) + P, \tag{7}$$

$$u_{3,i} = \sum_{m=1}^{M-1} B_{3,m} e^{-\beta_m x} \cos\left(\mu_m \left(i - 0,5\right)\right) + \frac{P}{EF} x, \tag{8}$$

$$p_{3,i} = -EF \sum_{m=1}^{M-1} B_{3,m} e^{-\beta_m x} \beta_m \cos\left(\mu_m\left(i-0,5\right)\right) + P, \tag{9}$$

where $A_{k,m}$, $B_{k,m}$ – constants of integration; k – segment number (takes value 1, 2, 3); E, F – respectively, the reduced tensile elastic modulus and the cross-sectional area of the cable; $\beta_m = \sqrt{2\frac{G\,b\,k_G}{(h-d)EF}[1-\cos(\mu_m)]}$; $\mu_m = \frac{\pi m}{M}$; $D_m = \frac{2}{M}\sum_{k=1}^{M} \varepsilon_k \cos\left(\mu_m\left(k-0,5\right)\right)$; h – distance between cables; b – rope thickness; d – cable diameter; G – shear modulus of the matrix; k_G – the coefficient of influence of the shape of the rubber, located between the cables on the shear stiffness; $A_{1,m} = \frac{D_m}{2\beta_m}\left(1-e^{-\beta_m L}\right)$; $A_{2,m} = -\frac{D_m}{2\beta_m e^{\beta_m L}}$; $B_{2,m} = \frac{D_m}{2\beta_m}$; $B_{3,m} = \frac{D_m}{2\beta_m}\left(1-e^{\beta_m L}\right)$.

Determination of unknown constants completes solving of the first problem.

The section of the cable damage moves relative to the drum. The curvature of the working surface of the drum maximally affects the redistribution of forces between cables at the cross section of the symmetry of the contact arc of the rope – in the section $x = L/2$. The tensile forces of the Θ-th cable in this section are determined by the following dependence:

$$p_{2,\Theta} = EF \sum_{m=1}^{M-1}\left[\left(A_{2,m} e^{\beta_m L/2} - B_{2,m} e^{-\beta_m L/2}\right)\beta_m + D_m\right]\cos\left(\mu_m\left(\Theta-0,5\right)\right) + P.$$

In the second problem, the sections of the beginning and end of the rope denote by L_I and L_{II}. Assume that in the cross section $x = l$ the Θ-th cable is damaged. In the extreme sections, the design features of the machine can create conditions under which it is known either distribution of displacements of the tractive elements, or the forces acting on them. Accordingly, in the cross-sections $x = L_I$ and $x = L_{II}$ it is possible to implement two pairs of boundary conditions: either $f_{I,n}(i)$ and $f_{I,c}(i)$, or either $f_{II,n}(i)$ and $f_{II,c}(i)$, or their combinations.

By the cut $x = l$ the rope is divided into two segments. Name these segments *I* and *II*. For displacements, distribution of tangential forces arising in rubber layers, we will provide special subscripts. Cables numbers designate by i $(1 \le i \le M)$. The segment number is denoted by the letter ρ (takes values *I* and *II*). The character of the boundary conditions is denoted by ϖ (takes values *c* or *n*).

The added state should not change the previous state at the boundaries $x = L_I$ and $x = L_{II}$. Find the solution in the following form [1]:

$$u_{i,\rho.\varpi} = \sum_{m=1}^{M-1}\left(a_{m,\rho.\varpi} e^{\beta_m x} + b_{m,\rho.\varpi} e^{-\beta_m x}\right)\cos\left(\mu_m\left(i-0,5\right)\right), \tag{10}$$

$$p_{i,\rho.\varpi} = EF \sum_{m=1}^{M-1}\left(a_{m,\rho.\varpi} e^{\beta_m x} - b_{m,\rho.\varpi} e^{-\beta_m x}\right)\beta_m \cos\left(\mu_m\left(i-0,5\right)\right), \tag{11}$$

where $a_{m,\rho.\varpi}$, $b_{m,\rho.\varpi}$ – constants of integration; ρ – segment number; ϖ – indication of boundary conditions.

If in the cross section $x = l$ the Θ-th cable is damaged, then the condition of compatibility of the deformation of the two segments must be fulfilled:

$$\begin{aligned} &u_{i,I,\varpi} - u_{i,II,\varpi} = \begin{cases} 0, & i \ne \Theta, \\ U_0, & i = \Theta, \end{cases} \\ &p_{i,I,\varpi} - p_{i,II,\varpi} = 0, \\ &p_{\Theta,I,\varpi} = -P_\Theta, \end{aligned} \tag{12}$$

where U_0 – unknown value of the gap between the ends of the damaged cable; P_Θ – internal load of the Θ-th cable before its damage in the cross section $x = l$.

The difference between displacements of the Θ-th cable of the first and the second segment is set by the discrete function:

$$u_{i,I,\varpi} - u_{i,II,\varpi} = 2\frac{U_0}{M}\sum_{m=1}^{M-1}\cos\left(\mu_m\left(\Theta-0,5\right)\right)\cos\left(\mu_m\left(i-0,5\right)\right). \tag{13}$$

Accepted function of difference of displacements, conditions of equality of tensile forces of a cable on both its segments, conditions of compatibility of their deformations (13) lead to two *M*-1 equations of four *m*-th constants:

$$\begin{aligned} &a_{m,I,\varpi} e^{\beta_m l} + b_{m,I,\varpi} e^{-\beta_m l} - a_{m,II,\varpi} e^{\beta_m l} - b_{m,II,\varpi} e^{-\beta_m l} = 2\frac{U_0}{M}\cos\left(\mu_m\left(\Theta-0,5\right)\right), \\ &a_{m,I,\varpi} e^{\beta_m l} - a_{m,II,\varpi} e^{\beta_m l} = \frac{U_0}{M}\cos\left(\mu_m\left(\Theta-0,5\right)\right) \end{aligned} \tag{14}$$

and dependencies

$$EF\sum_{m=1}^{M-1}\left(a_{m,I,\varpi}e^{\beta_m l}-b_{m,I,\varpi}e^{-\beta_m l}\right)\beta_m\cos\left(\mu_m\left(\Theta-0,5\right)\right)+P_\Theta=0. \tag{15}$$

Add to the noted equations the laws of the loading (deformation) of the rope in the cross sections $x = L_I$ and $x = L_{II}$ – boundary conditions. Let the last are given by the laws of the distribution of forces at the ends of the rope. Taking into account their values, we have the following solutions of the system of equations:

$$U_0=-\frac{2\sum_{m=1}^{M-1}\beta_m\cos\left(\mu_m\left(\Theta-0,5\right)\right)\left(\frac{e^{\beta_m\left(L_I-l\right)}}{\beta_m EF}\Lambda_{m,I,c}+\lambda_m\right)+\frac{MP_\Theta}{EF}}{\sum_{m=1}^{M-1}\beta_m\cos\left(\mu_m\left(\Theta-0,5\right)\right)^2\frac{\left(1+e^{2\beta_m\left(L_{II}-l\right)}\right)\left(e^{\beta_m l}-e^{\beta_m\left(2L_I-l\right)}\right)}{\left(e^{\beta_m\left(2L_I-l\right)}+e^{\beta_m\left(2L_{II}-l\right)}\right)}},$$

where $\lambda_m=\dfrac{\left(e^{\beta_m l}-e^{\beta_m\left(2L_I-l\right)}\right)\left(e^{\beta_m L_{II}}\Lambda_{m,II,n}+\dfrac{e^{\beta_m L_I}}{\beta_m EF}\Lambda_{m,I,c}\right)}{\left(e^{2\beta_m L_I}+e^{2\beta_m L_{II}}\right)}$;

$$a_{m,I.\varpi}=\frac{2\left(e^{\beta_m\left(L_{II}-l\right)}\Lambda_{m,II,n}+\dfrac{e^{\beta_m\left(L_I-l\right)}}{\beta_m EF}\Lambda_{m,I,c}\right)}{M\left(e^{\beta_m\left(2L_I-l\right)}+e^{\beta_m\left(2L_{II}-l\right)}\right)}+$$

$$+\frac{U_0\left(1+e^{2\beta_m\left(L_{II}-l\right)}\right)}{M\left(e^{\beta_m\left(2L_I-l\right)}+e^{\beta_m\left(2L_{II}-l\right)}\right)}\cos\left(\mu_m\left(\Theta-0,5\right)\right);$$

$$a_{m,II.\varpi}=a_{m,I.\varpi}-\frac{U_0}{Me^{\beta_m l}}\cos\left(\mu_m\left(\Theta-0,5\right)\right);$$

$$b_{m,I,c}=a_{m,I,c}e^{2\beta_m L_I}-\frac{2e^{\beta_m L_I}}{\beta_m MEF}\Lambda_{m,I,c};$$

$$b_{m,II,n}=\frac{2e^{\beta_m L_{II}}}{M}\Lambda_{m,II,n}-a_{m,II,n}e^{2\beta_m L_{II}}.$$

The obtained dependencies allow for the rope of a known construction, according to the known location of the damaged cable and the effort perceived by this cable before its destruction, to determine the stress-strain state of the rope of the hoist with the damaged cable.

In our example $L_I\to-\infty$, $L_{II}\to\infty$. In accordance with Saint-Venant's principle, local disturbances result in a local stress-strain state. Given the considerable distances between the section of damage of the cable and the boundaries of the segments, the relevant areas can be considered infinitely long. In the case of infinitely long first section should be taken $b_{m,I,\varpi}=0$. For an infinitely long the second – $a_{m,II,\varpi}=0$.

In the case of infinitely long both segments, the value of l (the coordinate of the cross section with the damaged cable) is small. It can be taken equal to zero, and the section of the rupture may be considered as the plane of symmetry. The symmetry of the stress-strain state allows the solution of the problem to be found only for one (first) segment. Let's miss its number. Find the solution in the following form:

$$u_i=\sum_{m=1}^{M-1}b_m e^{-\beta_m x}\cos\left(\mu_m\left(i-0,5\right)\right)+\frac{P_\Theta}{EF}x+\varepsilon, \tag{16}$$

$$p_i=\sum_{m=1}^{M-1}-b_m e^{-\beta_m x}\beta_m\cos\left(\mu_m\left(i-0,5\right)\right)EF+P_\Theta, \tag{17}$$

$$\sum_{m=1}^{M-1} b_m \cos\left(\mu_m (i-0,5)\right) + \varepsilon =$$
$$= U_0 \left(\frac{2}{M} \sum_{m=1}^{M-1} \cos\left(\mu_m (i-0,5)\right) \cos\left(\mu_m (\Theta - 0,5)\right) + \frac{1}{M} \right), \qquad (18)$$

where $U_0 = \dfrac{P_\Theta}{2EF \sum_{m=1}^{M-1} \cos\left(\mu_m (\Theta-0,5)\right)^2 \beta_m}$; $b_m = \dfrac{2}{M} U_0 \cos\left(\mu_m (\Theta - 0,5)\right)$; $\varepsilon = \dfrac{U_0}{M}$.

Recent dependencies are the result of solving the second problem in general form. Before the damage of the Θ-th cable, its load in the section of the gap was $P_\Theta = p_{2,\Theta}$. Accordingly, in the expressions (12), (15) - (17), instead of the value of the effort in the general form, it is necessary to substitute the value $p_{2,\Theta}$. Take into account the shear of the origin of the coordinate axis in the second problem relative to the first, and the symmetry of the solution in it. Add the obtained solutions. The distribution of forces in the cables will have the following expression:

$$p_i = EF \sum_{m=1}^{M-1} \left[\left(A_{2,m} e^{\beta_m x} - B_{2,m} e^{-\beta_m x} - b_m e^{-\beta_m \left(|x| - L/2\right)} \right) \beta_m + D_m \right] \times$$
$$\times \cos\left(\mu_m (i-0,5)\right) + P + p_{2,\Theta}. \qquad (19)$$

The obtained dependence determines the distribution of forces in the cables of the rubberized rope. It takes into account the design of the machine - the deviation of the drum generatrix of the hoisting machine from the straight line, and the breaking of the cable.

Damage of the cable leads to redistribution of forces among other cables. Internal forces, acting in cables adjacent to the damaged, are changing more. Extreme change of forces occurs in the section of damage of the cable. In the case under consideration – in the section $x = 0$. This allows determining the values of the coefficients of force concentration in two adjacent cables. The coefficients are assigned by the subscripts corresponding to the cables numbers, adjacent to the damaged:

$$k_{\Theta-1} = \frac{EF}{P} \sum_{m=1}^{M-1} R_m \cos\left(\mu_m (\Theta - 1,5)\right) + \frac{p_{2,\Theta}}{P} + 1, \qquad (20)$$

$$k_{\Theta+1} = \frac{EF}{P} \sum_{m=1}^{M-1} R_m \cos\left(\mu_m (\Theta + 0,5)\right) + \frac{p_{2,\Theta}}{P} + 1, \qquad (21)$$

where $R_m = \left(A_{2,m} - B_{2,m} - b_m e^{\beta_m L/2} \right) \beta_m + D_m$.

In case of damage of the extreme cable, when Θ = 1 or Θ = M, $k_{\Theta-1} = k_{\Theta+1}$, since the cosine function is symmetric. In the general case $k_{\Theta-1} \neq k_{\Theta+1}$. Then the coefficient of concentration of forces in the cable is equal to the greater of the determined.

Conclusions. The stress-strain state of the rope, caused by various factors, can be defined as a superposition of states provided that the boundary conditions remain unchanged. Comprehensive account of the influence of various factors, including destruction of cables, on the stress-strain state of the rope, allows correct determining the loss of its tractive capacity in the event of a breaking one of the cables. The loss of traction capacity of a rope can be estimated by determining greatest of two values of the coefficients of concentration of forces in cables adjacent to the damaged.

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МІЦНІСТЬ КОНВЕЄРНОЇ СТРІЧКИ ВІДВЕДЕННЯ ВОДИ ПІСЛЯ ПРОМИВАННЯ СИРОВИНИ / STRENGTH OF CONVEYOR BELT OF WATER DRAINAGE AFTER RINSING OF RAW MATERIAL

Білоус О.І., канд. техн. наук, доцент
Перфильєва Ю.М., інженер
Дніпровський державний технічний університет, Україна

Учасники конференції

Досліджено напружений стан стрічки утвореної системою паралельних тягових елементів запресованих в еластичну оболонку. На підставі розв'язання системи лінійних диференційних рівнянь рівноваги тягових елементів встановлено, механізм, закономірності та коефіцієнти нерівномірності розподілу внутрішніх сил розтягування тягових елементів в стрічці з отворами. Запропоновано спосіб визначення тягової спроможності стрічки з отворами.
Ключові слова: *Стрічка конвеєра, отвори, механічні властивості, тягові елементи, коефіцієнт концентрації сил.*
Investigated the stress state of the tape formed by a system of parallel traction elements are pressed into the elastic shell. On the basis of solutions of systems of linear differential equations of equilibrium of traction elements are mounted, mechanism, patterns and coefficients of uneven distribution of internal forces of stretching of traction elements in a ribbon with apertures. The proposed method of determining the traction capacity of the belt with holes.
Keywords. *Conveyor belt, holes, mechanical properties of traction elements, the coefficient of concentration of forces.*

Вступ. Суміщення технологічних процесів миття та транспортування продукції підвищує ефективність виробництва та рівень його механізації. В процесі переміщення похилим стрічковим конвеєром залишки води стікають стрічкою. На горизонтальному конвеєрі вона переміщається разом із завантаженою насипом сільськогосподарською сировиною. Для відведення зайвої вологи під час транспортування доцільно застосувати стрічку з отворами [1]. Використання стрічок масового виробництва, в яких виконані спеціальні отвори, дозволяє вирішити задачу виробництва стрічок для конвеєрів часткового зневоднення сировини та вимагає дослідження впливу отворів на їх тягову спроможність.

Постановка задачі. Сільськогосподарська сировина здебільшого має форму близьку до сфери. У разі розташування окремого плода що транспортується на межі отвору, він опуститься в нього. Якщо діаметр отвору перевищить діаметр окремого плоду, він випаде. В протилежному випадку, перекриє отвір і зменшить можливість відведення вологи. Для уникнення останнього, доцільно отвори виконувати не круглими, а наприклад, прямокутними. При цьому одна зі сторін прямокутних отворів має бути меншою за мінімальний розмір окремого плоду. Інша може бути довільною. Для забезпечення рівномірного відведення вологи по довжині стрічки, що рухається конвеєром, отвори мають бути розташовані регулярно. Здатність стрічки пропускати вологу залежить від характеру розподілу отворів по ширині стрічки та їх сумарної площі. Бокові сторони стрічки нахилені для надання їй жолобчатої форми. Відведення вологи здебільшого відбувається в середній частині стрічки. В цій частині мають бути передбачені отвори.

Конвеєрні стрічки армовані. Вони мають поздовжні регулярно розташовані елементи армування - тягові елементи запресовані в еластичну оболонку. Механічні властивості стрічки, включно і її міцність, визначаються кількістю, взаємним розташуванням, механічними параметрами елементів армування та матеріалу оболонки. Виконання отворів в таких стрічках пов'язане з частковим видалення елементів армування та зменшенням її тягової спроможності. В роботі поставлена задача визначити зменшення тягової спроможності стрічки конвеєра з регулярно розташованими отворами за довільної схеми їх розташування та розмірів.

Результати роботи. Розглянемо стрічку з прямокутними, регулярно розташованими отворами розмірами $l \times b$. Вісь x спрямуємо вздовж стрічки. Початок осі розташуємо на межі довільного ряду отворів. Тяговим елементам надамо номери від одиниці до $M+N$. Подовжні елементи армування позначимо потовщеними лініями (рис. 1). Лінією з розривами покажемо симетричну частину повторюваного елемента стрічки з системою отворів розташованих з постійними кроками як вздовж так і по її ширині.

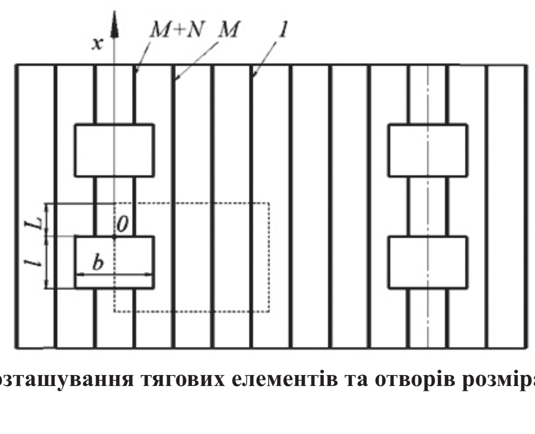

Рис. 1. Схема розташування тягових елементів та отворів розмірами $l \times b$ стрічки