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REGARDING THE ISSUE OF POST-WAR DEVELOPMENT OF MINING REGIONS AND RESTORATION OF DESTROYED INFRASTRUCTURE FACILITIES

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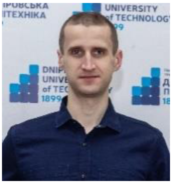

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Abstract

The subject of the study is the patterns of interaction and distribution of forces between reinforcement elements as fibers of a composite structure of regular structure, as well as hydrogeodynamic, energy and geometric parameters of disturbed soil massifs during the restoration of destroyed infrastructure facilities.

The purpose of the work is to simplify and speed up the commissioning of bridge structures with span structures destroyed as a result of military operations based on the scientific justification of a single complex technology for their rapid restoration using composite cable ropes of domestic production.

As an alternative to the complete restoration of destroyed bridges, it is proposed to use cable-stayed structures in whole or in part. As bridge cables, it is proposed to use well-known rubber composite ropes, the production of which has been established in Ukraine. The reliability of the proposed ropes can be increased by increasing the number of ropes in them.

A model and algorithm for calculating the stress-deformed state of a rubber cable rope of an arbitrary design has been developed, taking into account the nonlinear deformation of the cables and the presence of a discontinuity of an arbitrarily located cable. The model was built using the methods of mechanics of composite materials. It is solved analytically in a closed form.

Key words: post-war infrastructure restoration, cable-stayed bridges, rubber-cable ropes, composite materials, tower excavator.

Introduction

An important component of sustainable economic development, especially in mining regions, is a developed infrastructure, in particular a transport network. Both products for sale and equipment and materials for production needs are delivered by roads, tunnels and bridges. Serious damage to the transport infrastructure leads to disruption of supplies. This becomes the cause of production downtime, due to which the enterprise bears colossal losses [1–3].

According to Ukravtodor, more than 150 bridges and overpasses were destroyed because of the war in Ukraine, including in Chernihiv region – 27. In Kharkiv region – 25, in Kyiv region – 24. Traffic has already been restored on 76 bridges. This means that detours or temporary crossings have been built near the destroyed buildings. According to the latest estimates, it will take about 4 years to rebuild the entire destroyed infrastructure of Ukraine. [4]

Bridge crossings are the most important component of the country's logistics system. The main form of their destruction during military operations is the damage to the fabric and the destruction of overhead structures. The restoration of destroyed bridges is the most important and primary task of the state policy to ensure the independence and national security of Ukraine.

In addition, a very important issue is the search for domestically produced materials for the restoration of bridges. This will contribute to the reduction of costs for the post-war reconstruction of Ukraine, and at the same time stimulate the development of its own industry, in particular mining, construction and machine-building.

Analysis of bridge destructions in Ukraine.

After the de-occupation of its territories, the critical infrastructure is being gradually restored in Ukraine. For this, damaged roads and destroyed bridges are being restored as a priority. It is easiest and fastest to restore transport connections through the channels of small rivers.

One of the ways to build a crossing across a small river is to lay rigid polypropylene pipes of large diameter on the bottom of the river along the direction of its flow (fig. 1). The top is densely covered with screening, asphalt is laid. The banks of the river are strengthened by rock mining mass of a large fraction.

Such a crossing provides the passage of small cars, pedestrian connection of the shores. Moreover, the constructed crossing does not impede the flow of the river. However, such a solution is temporary, and later this crossing will collapse under the influence of precipitation and groundwater. Intensive movement of such a crossing, especially heavy-duty vehicles, is impossible.

Fig. 1. Construction of a crossing over the Ingulets River connecting the village of Zarichne with Arkhangelsky of the Visokopil community [5]

There is also a solution that involves the rapid construction of a full-fledged bridge. For this purpose, a detour of the destroyed bridge with a descent along the river bank is being built (fig. 2). The created detour is connected by a bridge with smaller supports and a flight, as it is located below the destroyed bridge, closer to the bottom of the river.

It is obvious that such a decision is temporary, because there is a threat of rising water level, as a result of which the bridge may be flooded. In addition, such a detour is the cause of a dangerous traffic factor, namely, limited visibility due to the shape of the detour route and the presence of a destroyed bridge.

Fig. 2. Temporary bridge across the Siverskyi Donets River (Izyum, Kharkiv Region) [6]

The cases described above are the most frequent. For them, it is possible to find a quick temporary solution. However, there is also the problem of broken long bridges across wide rivers. In the vast majority of such bridges, one or more spans were destroyed and supports near one of the banks of the river were damaged (fig. 3). While part of the bridge on the opposite bank is almost undamaged.

Such destruction, as a rule, is the result of blowing up the bridge before the retreat of the army that previously controlled it. The destruction of the spans of the long bridge requires a complete reconstruction of the destroyed part of it. The temporary measures described above do not work in this case.

Fig. 3. The destroyed bridge over the Dnipro River.
Frame from the movie "RIK" ("The Year", 2023) [7]

There are cases when the bridge is completely destroyed. At the same time, the river is not very wide, but it is not narrow enough to build a temporary bridge, as shown in the photo (fig. 2) or crossing (fig. 1). In the Kherson region, the Daryiv Bridge (fig. 4) across the Ingulets River can be restored in 1-3 months. These works will cost an average of 60-80 million hryvnias.

Fig. 4. The destroyed Darivskyi road bridge across
the Ingulets River (Kherson Region) [8]

The destruction of very long bridges, such as the Antonivsky bridge, is possible when the central spans are destroyed (fig. 5). At the same time, the elimination of such damage is complicated by the intensity of the river flow in the place of destruction.

Fig. 5. The ruined Antoniv bridge across the Dnipro River
Frame from the movie "RIK" ("The Year", 2023) [9]

An analysis of the destruction of bridges caused by hostilities in Ukraine showed that the vast majority of damaged objects are small bridges, the restoration of which does not take much time. In addition, temporary measures are being implemented that allow us to restore transport connections in critical sections by our own efforts. Temporary crossings and bridges are located below the destroyed ones, due to which there is a threat of their flooding.

There are no temporary solutions for the rehabilitation of large bridges. For their restoration, it is necessary to attract a significant amount of funds, including international aid. However, such bridges do not collapse completely. Therefore, the not destroyed part can be used in the restoration of the bridge.

While for small bridges, a temporary solution is to build a crossing below the destroyed bridge, for large bridges, such a solution can be the construction of the destroyed sections of the pylon of the cable-stayed bridge. Since the construction of such bridges requires imported components, and there are a lot of destroyed objects, it is necessary to rely on the use of alternative materials of domestic production.

Schemes of cable-stayed bridges.

Cable-stayed bridges are called bridges, the main elements of span structures of which are inclined rectilinear cables that suspend stiffening beams from pylons (fig. 6).

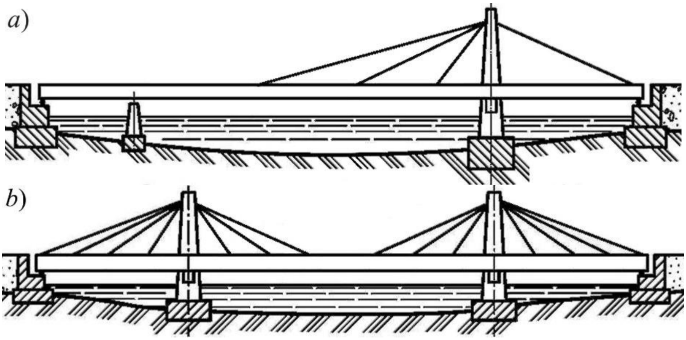

Fig. 6. Cable-stayed bridges with one (*a*) and two (*b*) pylons

Inclined cables are attached to the pylons and support the stiffness beam, being elastic supports for it. A special role is played by the outer cables connecting the top of the pylon with a fixed point. They prevent the horizontal movement of the top of the pylon under the action of temporary loads and provide the system with great rigidity in the vertical plane. The cables work only in tension, the pylons - mainly in compression, the stiffening beam - in bending and on the effect of horizontal forces, which are in the cables. The stiffening beam is supported by cables in many places and works as if on an elastic basis, it does not have significant bending moments, so it can have a small height. It can rest on pylons, in which case significant negative moments arise in the area of what is being supported. To avoid them, recently they began to abandon the fact that it rests on the pylons, transferring the weight of the stiffness beam and the temporary load to the pylons only through the cables.

Cable-stayed bridges with reinforced concrete stiffening beams and pylons began to be used recently. The first of them was built in Venezuela across the lake. Maracaibo in 1962, the second - across the harbor of the Dnipro River in Kyiv in 1963 (Fishing cable-stayed bridge). To date, there are more than 80 cable-stayed reinforced concrete bridges in the world, but they have significant prospects for development. They make it possible to cover spans of more than 1000 m. They are usually erected at the intersection of deep rivers, sea bays or straits, at the mouth of rivers, where the construction of supports is difficult. By 1986, in reinforced concrete cable-stayed bridges, a record span of 440 m will be achieved in a bridge built in

1983 in Spain (bridge Los Barrios de Luna). In 2024, the longest cable-stayed bridge will be Changtai Yangtze River Bridge, 1,176 m long in Jiangsu, China.

Three cable-stayed bridges have now been opened in Ukraine: two in Kyiv (South and North), one in Zaporizhzhia New bridge across the Dnipro. The above-mentioned Rybalsky cable-stayed bridge was decommissioned in 2009. 1256 m length South bridge opened in 1990, 816 m length North bridge opened in 1976, 660 m length New bridge in Zaporizhzhia across the Dnipro opened in 2022. At the beginning of 2022, under the President's program "Big construction", the construction of the New Kremenchug bridge over Dnipro Two reinforced concrete pylons with a total height of 115 m were built. A concrete plant with a capacity of 160 m^3/h was built for construction needs. [10]. This indicates the rapid development of the bridge construction industry in Ukraine.

The schemes of cable-stayed bridges are distinguished depending on the number of pylons, the system, and the number of planes of cables. With one pylon (Fig. 6*a*), the cables are located asymmetrically relative to it, they are attached to the stiffness beam in the main span at different angles. This requires different structural solutions of their fastening nodes, and the presence of small attachment angles leads to the occurrence of large forces in the cables and a decrease in the rigidity of the span structure. However, the scheme with one pylon turns out to be acceptable in urban conditions for architectural reasons, as it can fit into the ensemble of the terrain and buildings of the city near the river.

The pylon of the cable-stayed bridge can be tilted to the vertical. In addition to the architectural effect, it allows to transfer part of the horizontal force from the cables of the main span to the pylon. In single-pylon bridges, the end cables can be attached to the foundations. In this case, the stiffening beam rests against one of the foundations, transferring a horizontal force to it.

Cable-stayed bridges with two pylons (Fig. 6*b*), the outermost cables of which are fixed to the ends of the stiffening beam, work as systems with a perceived gap in the stiffening beam. They have mainly vertical forces transmitted to the pylons from the cables, since their cables are located symmetrically with respect to the pylons. Angles of inclination of the cables are taken at least 30°, so that they do not have significant forces and deformations. The stiffness beam in these bridges can be supported in many points, which is favorable for its operation.

The distances between the points of attachment of the cables to the stiffening beam vary widely: from 5-10 to 50-60 m. Depending on this, the height of the stiffening beam changes. It is usually taken constant along the entire length.

In cable-stayed bridges, various systems of positioning of cables are used. Two cable systems are most often used: "bundle" and "harp". In the "bundle" system (Fig. 7*a*), the cables converge in the upper part of the pylon in one horizontal plane. With many them, it complicates the knot of attaching them to the pylon. In this system, the ropes have different angles of attachment to the stiffness beam, the middle ropes are more inclined to it, which helps to reduce the forces arising in them. With the presence of extreme support cables in this system, there are no bending moments in the pylons, they work only in compression. In the "harp" system (Fig. 7*b*), the cables are attached to the pylon in several levels and have the same slope to the stiffness beam. The knots for fastening the cables to the stiffness beam and to the pylon in it are of the same type. With many cables, this system allows you to unify the knots of fastening the cables to the stiffening beam and to the pylon, unify the elements of the stiffening beam and effectively use the possibilities of their industrial production and construction. However, with one-sided loading of the main span, the pylon works intensively to bend due to the horizontal forces in the cables.

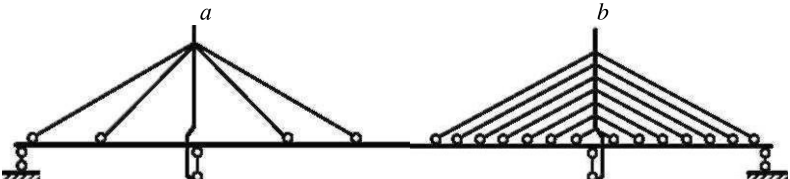

Fig. 7. Schemes of the arrangement of cables in bridges:
a – bundle shape; *b* – harp

In the cross-section of the span structure, the cables are placed in one or two planes. In wide bridges, a larger number of their planes is possible. The number of cable planes and the number of cables in one plane have a significant impact on the architectural merits of the bridge, on the operation and construction of the stiffening beam and pylons.

Types of cable-stayed bridge pylons.

When placing the cables in two planes, П-shaped, A-shaped and two-post pylons are used (Fig. 8*a,b,c*), the driving part is placed between them, and the sidewalks are carried on the console beyond the planes of the cables. When using A-shaped pylons, the cables are placed in two inclined planes, and when using П-shaped pylons, they are placed in two vertical planes. The two planes of the cables make it possible to disperse and reduce the forces in the stiffening beam and in the cables, to ensure favorable operating conditions for the stiffening beam when it is loaded asymmetrically with respect to the longitudinal axis. With two planes of the cables, the stiffness beam can have a small torsional stiffness and be made of tile or ribbed elements.

When placing cables in one plane, single-post (Fig. 8*d*) or A-shaped (Fig. 8*e,f*) pylons are used. In this case, single-post pylons and cables are placed within the width of the dividing strip between the carriageways of the two directions of traffic. Single-post pylons require less material and are easier to manufacture, but the node of their intersection with the stiffening beam is complicated: the pylon must be passed through the stiffening beam while preserving its bearing capacity in the weakening zone. A-shaped pylons (Fig. 8*e,f*) are more difficult to manufacture, but provide free passage of the stiffness beam between its posts and have greater stiffness in the transverse direction.

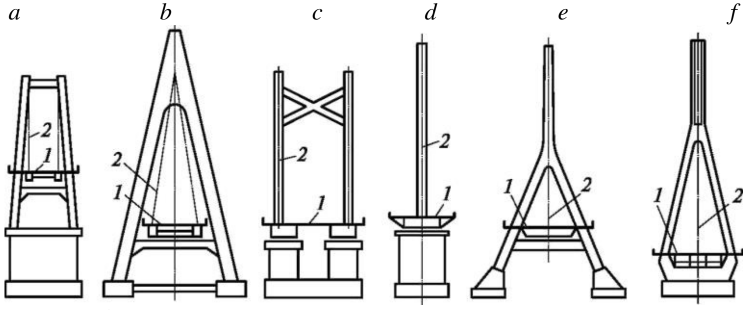

Fig. 8. Constructive forms of pylons in the cross section of an overpass with two (*a–c*) and one (*d–f*) planes of cables: *1* – stiffness beam; *2* - the plane of the cable location

A stiffening beam with one plane of the cables and its asymmetric loading works not only for bending, but also for torsion and should have significant torsional stiffness. The height of the pylons of cable-stayed bridges is taken on the condition that the angle of inclination of the furthest cable-stay is at least 30°.

Construction of cable-stayed bridge elements.

The design of the stiffening beams mainly depends on the width of the carriageway, the number of cable planes, the distance between the points of fastening of the cables and a little on the size of the main span. When the number of cables in one plane increases, it becomes possible to make stiffening beams even from simple unified elements used in simple beam bridges. With two planes of cables, depending on the width of the carriageway and the number of cables in one plane, the stiffening beams can be tiled, ribbed and box-shaped.

Tile stiffeners of cable-stayed pedestrian bridges can be made of unified hollow tile blocks, if the distance between the points of attachment of the cables does not exceed 15…18 m, and the width of the carriageway does not exceed 8 m. longitudinal - monolithic transverse beams. Transverse beams perceive a moment that also bends, acting in the transverse direction; they are also used to attach the stiffening plate to the cables.

As the main span increases, the normal force compressing the stiffening beam increases almost linearly. For its perception, it is necessary to perform a beam of rigidity with a greater height. If the distance between the points of fastening of the cables is 15...30 m, the stiffening beam can be formed from unified I-beams, connecting them at the points of fastening of the cables with transverse monolithic beams - diaphragms capable of perceiving the bending moment in the transverse direction, perceiving the forces from the cables in an inclined plane and transfer them to the longitudinal beams, components of the stiffness beam.

At the same distances between the points of fastening of the cables, a stiffening beam was used, consisting of two widely spaced П-shaped beams, on which the transverse beams of the carriageway are laid. The extreme beams are placed in the planes of the cables, have transverse diaphragms to which the cables are attached. This design of the stiffening beam was first used in the cable-stayed bridge across the Dnipro harbor in Kyiv.

When the width of the carriageway is more than 12 m, it is advisable to use stiffening beams of box section, which have significant torsional stiffness. With a single-plane cable system, only the box-shaped cross-section of the stiffening beam can reliably resist bending and twisting. Box beams have great stiffness during bending and twisting, are equally well adapted to the perception of both positive and negative moments, have good aerodynamic parameters, have an attractive appearance, are convenient for transportation and installation.

Justification of the type of cable-stayed ropes.

Restoration of the destroyed span structures of bridge crossings requires significant material costs and time, as they must have significant bending stiffness in terms of strength and stiffness. Cable-stayed bridges require significantly less rigidity. Depending on the design of the cable-stayed bridge, ropes of different strength and, accordingly, different designs should be used. Cable ropes are not produced in Ukraine, however, the production of composite rubber-cable ropes for the mining industry has been established.

The practice of use under the influence of mining waters and abrasive wear has shown their considerable durability. Accordingly, there is an opportunity to create and manufacture a wide range of composite multi-layer cable-stayed ropes of different tensile strength for holding span structures of bridge structures, which requires scientific and technical justification. The use of such approaches in combination with the use of new materials and structures corresponds to modern world trends, and for Ukraine it is decisive for the strategy of military, post-war, urban, and industrial construction.

To solve the most important problem of the accelerated restoration of destroyed bridge crossings, the development of scientific and applied principles for the creation of a complex technology for the rapid restoration of bridges with destroyed span structures based on the use of composite multi-layer cable ropes of domestic production is relevant.

In Ukraine, most of the roads were built more than 50 years ago. Small and medium-sized bridges on highways are made of prefabricated string concrete diaphragm beams [11–16]. In our opinion, a promising technology for the restoration of bridges destroyed because of military operations is restoration by replacing span structures of bridges with cable-stayed ones as spatial steel-reinforced concrete structures [17-21].

One of the problems of implementing such an engineering solution is the use of the support system of the destroyed bridge and ensuring its reliability during the life cycle. There are at least two options for restoring spans of destroyed bridges: with the installation of a pylon on one of the banks of the river (fig. 9*a*) or with the location of a pylon on an artificially created island (fig. 9*b*).

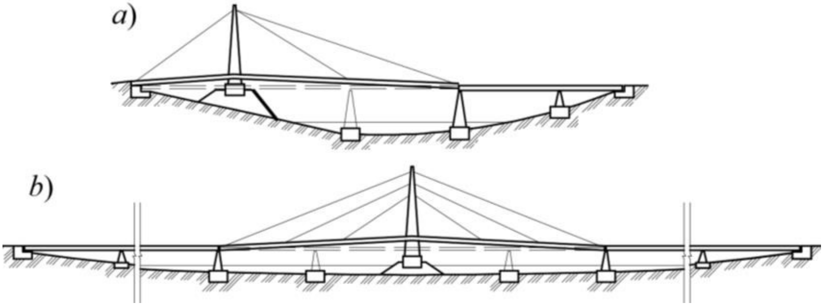

Fig. 9. Schemes of restoration of destroyed bridge spans using pylons with their location on the riverbank (*a*), on an artificial island (*b*)

The given scheme can use the existing, restored or reconstructed supports of the destroyed bridge. Different support systems of a collapsed bridge require different schemes of cable-stayed bridges. The above allows us to state that the developed structures of cable-stayed bridges can be adapted to various layout schemes and surviving supports (their foundations) of destroyed bridges. However, the application of such a proposal is associated with a number of problems:

- the production of wire ropes of a significant range of strength (diameters) requires the involvement of a significant number of suppliers or the construction of facilities with a wide range of production of ropes of various diameters;

- significant resistance to wind (horizontal) loads, accordingly additional deformation of the ropes;

- the reliability of the cable rope can be increased only by increasing its diameter, which leads to an increase in the above-mentioned drawback;

- a rope of a large diameter has a significant bending stiffness, its winding is possible only on coils of a large diameter;
- the influence of the environment on the rope requires its special protection.

In our opinion, a comprehensive solution to these problems is possible by replacing round cable ropes with flat ones, namely rubber-cable ropes (fig. 10). They use small cables of the same diameter as the rope.

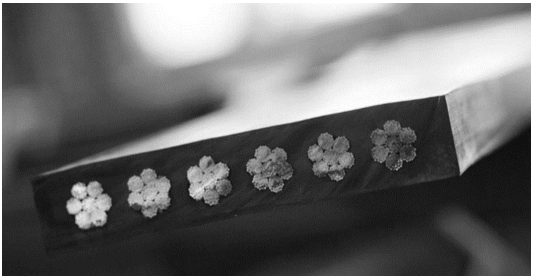

Fig. 10. Rubber-cable rope

The specified strength of the rope can be ensured by the number of cables in it. In addition, the production of such ropes has been established in Ukraine (fig 11).

A rope of a given profile can be formed by gluing single-layer ropes into several layers directly at the installation site. The parallel use of ropes in one rope as in a system with parallel connection and incomplete redundancy allows to ensure the specified durability of the rope by selecting the number of ropes in the rope.

The presence of rubber between the cables allows the method of controlling the electrical resistance measured between the ends of the cables to automatically determine breaks in individual cables during the life cycle, which increases the reliability of its operation. Studies on the substantiation of the method of controlling the electrical resistance of the wire rope are being conducted [22-32].

Today, it is necessary to develop and implement a technology in which to replace the rubber that connects the cables into a single system with another elastic material suitable for use in conditions of natural environmental influences on it.

Within the scope of this technology, it is envisaged to glue flat ropes into a cable rope using portable presses and to give the section of the cable rope an aerodynamic shape.

Methodology of stress-strain state calculating.

We will accept the following calculation scheme. A system of M parallel, flexurally rigid elastic rods of length L interacts through an elastic continuous medium in which tangential stresses arise.

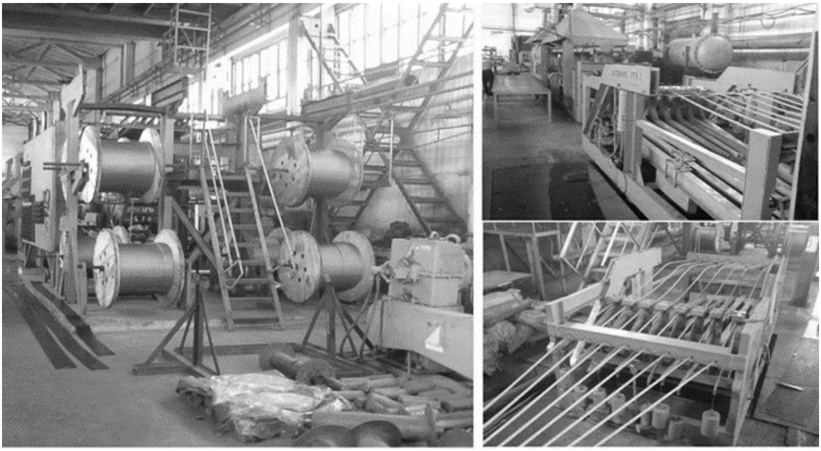

Fig. 11. Line to produce rubber-cable ropes in Kryvyi Rih

Deformation occurs within the linear law. One cable (j^{th}) has a distance discontinuity l $(0 < l < L)$ from the section of fixing the cables. The force P acts on the rope [33].

The solution to the problem looks like this [8, 9]

$$u_i = \sum_{m-1}^{M-1}\left(A_m e^{\beta_m x} + B_m e^{-\beta_m x}\right)\cos\left(\mu_m\left(i-0,5\right)\right) + \frac{Px}{EF} + \varepsilon, \quad (1)$$

where A_m, B_m, ε – unknown constants; M – number of cables in the rope; P – tensile strength of the cable; $\mu_m = \pi m/M$; $\beta_m = \pm\sqrt{2\left(\left(Gbk_G\right)/\left(hEF\right)\right)\left(1-\cos\left(\mu_m\right)\right)}$; b – rope thickness; c – the step of the arrangement of the cables in the rope; d – cable diameter; G – shear modulus of the rope rubber sheath material; k_G – coefficient that takes into account the cross-sectional shape of the rubber shell; h – the minimum distance between adjacent cables of the rope; E, F – composite modulus of elasticity for tension of the cable material and their cross-sectional area.

Rope tensile

$$p_i = EF\sum_{m=1}^{M-1}\left(A_m e^{\beta_m x} - B_m e^{-\beta_m x}\right)\beta_{m,k}\cos\left(\mu_m\left(i-0,5\right)\right) + P. \quad (2)$$

Ropes are attached to structural elements of lifting complexes, capital structures. The connection conditions depend on the design of the connection nodes. We will solve the problem of determining the stress-strain state in a general way – without specifying the conditions for connecting the ends of the rope. According to the task, the rope has a break in the continuity of the rope. This makes it impossible to make decisions (1) and (2) for the rope as a whole. We will apply separate solutions for two parts of the rope. For the first $0 \le x \le l$ and the second $l \le x \le L$ parts of the rope. We will give them the numbers 1 and 2. We will indicate the numbers in the lower index of the value that applies only to the specified part. We will record the movement and load of the cables of the second part in the following forms

$$u_{i,2} = \sum_{m-1}^{M-1} \left(A_{m,2} e^{\beta_m x} + B_{m,2} e^{-\beta_m x} \right) \cos\left(\mu_m \left(i - 0{,}5 \right) \right) + \frac{P x}{E F} + \varepsilon_2 , \quad (3)$$

$$p_{i,2} = EF \sum_{m=1}^{M-1} \left(A_{m,2} e^{\beta_m x} - B_{m,2} e^{-\beta_m x} \right) \beta_{m,k} \cos\left(\mu_m \left(i - 0{,}5 \right) \right) + P. \quad (4)$$

The parts of the rope form a single rope of length *L*. In the section $x=l$, the conditions must be fulfilled

$$p_{i,1} = p_{i,2} \qquad \left(1 \le i \le M \right), \quad (5)$$

$$p_{j,1} = p_{j,2} = 0 . \quad (6)$$

The size of the gap between the cables in the section of the break depends on the load on the rope. Let's conditionally accept it equal to one. The condition for the occurrence of a single gap between the ends of the damaged cable

$$u_{i,1} - u_{i,2} = \begin{cases} 0 & \left(i \ne j \right) \\ 1 & \left(i = j \right) \end{cases} , \quad (7)$$

where j - cable number with a break in continuity in the section $x = l$.

We equate the last condition with the δ-function. It is given by the Fourier series on the discrete axis of the numbers of cables of limited length:

$$u_{i,1} - u_{i,2} = \frac{2}{M} \cos\left(\mu_m \left(i - 0{,}5 \right) \right) + \frac{1}{M} . \quad (8)$$

From conditions (5) and (7), we have the following relations:

$$A_{m,1} - B_{m,1}e^{-2\beta_m l} - A_{m,2} + B_{m,2}e^{-2\beta_m l} = 0\,, \quad (9)$$

$$A_{m,1} + B_{m,1}e^{-2\beta_m l} - A_{m,2} - B_{m,2}e^{-2\beta_m l} = \frac{2}{Me^{\beta_m l}}\cos\left(\mu_m\left(j-0{,}5\right)\right), \quad (10)$$

$$\varepsilon_1 - \varepsilon_2 = \frac{1}{M}\,. \quad (11)$$

After simplifying the expressions (9), (10), we obtain:

$$A_{m,1} = A_{m,2} + \frac{\cos\left(\mu_m\left(j-0{,}5\right)\right)}{M\,e^{\beta_m l}}, \quad (12)$$

$$B_{m,1} = B_{m,2} + \frac{\cos\left(\mu_m\left(j-0{,}5\right)\right)}{M}e^{\beta_m l}\,. \quad (13)$$

Let's assume that there are no displacements of the first part $\varepsilon_1 = 0$. Then

$$\varepsilon_2 = -\frac{1}{M} \quad (14)$$

We consider expressions (9) and (10). Let's write down the value of the loading force of the jth cable in the section $x = l$. According to (6), the internal load force of the cable should be zero. To do this, multiply the first component of expression (2) by the ratio of the real value of the gap between the ropes and the one taken in condition (7). Consider (12), (13):

$$p_{i,1} = E\,F\sum_{m=1}^{M-1}\begin{pmatrix} A_{m,2}e^{\beta_m x} + \dfrac{\cos\left(\mu_m\left(j-0{,}5\right)\right)}{M} - \\ -B_{m,2}e^{-\beta_m x} - \dfrac{\cos\left(\mu_m\left(j-0{,}5\right)\right)}{M} \end{pmatrix}\cdot \quad (15)$$

$$\cdot\beta_{m,k}\cos\left(\mu_m\left(i-0{,}5\right)\right)Q + P,$$

where:

$$Q = -P\left[\frac{E\,F}{M}\sum_{m=1}^{M-1}\begin{pmatrix} A_{m,2}e^{\beta_m l} + \cos\left(\mu_m\left(j-0{,}5\right)\right) - \\ -B_{m,2}e^{-\beta_m l} - \cos\left(\mu_m\left(j-0{,}5\right)\right) \end{pmatrix}\cdot\right. \quad (16)$$

$$\left.\cdot\beta_{m,k}\cos\left(\mu_m\left(j-0{,}5\right)\right)\right]^{-1}$$

Accordingly, in other expressions for the distribution of forces and movements of cables of the first and second parts, the components of the expressions dependent on the number of the cable must be multiplied by the specified ratio. They determine the tension-deformed state of a rope with a damaged cable.

Two vectors of unknown constants remain unknown in the obtained solutions. They should be determined from the conditions of fixing the ends of the rope in the lifting installation or on the capital structure. These calculations complete the first part of the algorithm for calculating the stress-strain state of the rubber-cable rope.

Consider the influence of the nonlinear dependence of the modulus of elasticity on the applied force. Consider the second part of the algorithm. The lack of resistance to deformation of the damaged cable is accompanied by a redistribution of internal load forces between other (whole) cables. According to the Saint-Venant principle, a local change in the shape of a rigid body, as well as the application of a concentrated force, leads to a local redistribution of forces in an elastic body - in a rope. The internal load forces of the cables adjacent to the damaged one increase significantly. The tension in the cables adjacent to the damaged one is significantly (up to 60-40%) higher than the average.

It is known that the modulus of elasticity of materials depends on the load force, when the stresses in the loaded sample exceed a certain value - the limit of elasticity. Accordingly, the non-linear deformation of ropes with an uneven distribution of forces between the ropes can be modeled linearly, in which the deformations are considered unchanged, and the maximum forces are taken as reduced in proportion to the ratio of the modulus of elasticity, which corresponds to the actual load to its linear value.

The law of decreasing internal load forces of maximally loaded ropes is given by the product of Fourier series in continuous coordinates on the first and second parts in the intervals $0 \le x \le l$ and $l \le x \le L$ and in discrete coordinates of cable numbers, limited by their number. Thus, the model of the deformed state and the obtained dependencies for the case of linear deformation of the rope (1), (3) remain unchanged. Ratios (12), (13) obtained from the conditions of simultaneous deformation remain unchanged. Expression (14) will depend on the quantity ψ тросів, cables adjacent to the damaged one:

$$\varepsilon_2 = -\frac{\psi}{M}. \tag{17}$$

Expressions of internal load forces of cables (2), (4) are written in the following forms:

$$p_{i,1} = EF\sum_{m=1}^{M-1}\left[\begin{array}{l}\left(\begin{array}{l}\left(A_{m,2}+\dfrac{\cos\left(\mu_m\left(j-0{,}5\right)\right)}{M\,e^{\beta_m l}}\right)e^{\beta_m x}-\\ -\left(B_{m,2}+\dfrac{\cos\left(\mu_m\left(j-0{,}5\right)\right)}{M}e^{\beta_m l}\right)e^{-\beta_m x}\end{array}\right)\beta_{m,k}-\\ -\displaystyle\sum_{k=0}^{K}C_{k,1}\cos\left(\frac{\pi kx}{l}\right)\left(\begin{array}{l}\cos\left(\mu_m\left(j-1{,}5\right)\right)+\\ +\phi\cos\left(\mu_m\left(j+0{,}5\right)\right)\end{array}\right)\end{array}\right]\cdot, \tag{18}$$

$$\cdot\cos\left(\mu_m\left(i-0{,}5\right)\right)+P$$

$$p_{i,2} = EF\sum_{m=1}^{M-1}\left[\begin{array}{l}\left(A_{m,2}e^{\beta_m x}-B_{m,2}e^{-\beta_m x}\right)\beta_{m,k}-\\ -\displaystyle\sum_{k=0}^{K}C_{k,2}\cos\left(\frac{\pi kx}{L-l}\right)\left(\begin{array}{l}\cos\left(\mu_m\left(j-1{,}5\right)\right)+\\ +\phi\cos\left(\mu_m\left(j+0{,}5\right)\right)\end{array}\right)\end{array}\right]\cdot,$$

$$\cdot\cos\left(\mu_m\left(i-0{,}5\right)\right)+P \tag{19}$$

where $C_{k,1}$, $C_{k,2}$ - coefficients of the Fourier series, which take into account the difference between the linear modulus of elasticity of the cable and the real one, depending on the load; ϕ – the coefficient of proportionality of the load forces of the $(j+1)^{\text{th}}$ cable relative to the $(j{-}1^{\text{th}})$.

From the condition of equality of forces (5), the condition of equality between the coefficients must be ensured:

$$\sum_{k=0}^{K}C_{k,}\cos\left(\pi k\right)=\sum_{k=0}^{K}C_{k,2}\cos\left(\frac{\pi kl}{L-l}\right). \tag{20}$$

The value of the Q coefficient will change. It will be determined by the following dependence:

$$Q=-P\left[\sum_{m=1}^{M-1}EF\left(\begin{array}{l}\left(\begin{array}{l}M\,A_{m,2}e^{\beta_m l}+\cos\left(\mu_m\left(j-0{,}5\right)\right)-\\-M\,B_{m,2}e^{-\beta_m l}-\cos\left(\mu_m\left(j-0{,}5\right)\right)\end{array}\right)\dfrac{\beta_{m,k}}{M}-\\-\sum_{k=0}^{K}C_{k,1}\cos\left(\pi k\right)\left(\begin{array}{l}\cos\left(\mu_m\left(j-1{,}5\right)\right)+\\+\phi\cos\left(\mu_m\left(j+0{,}5\right)\right)\end{array}\right)\end{array}\right)\cdot\right.$$

$$\left.\cdot\cos\left(\mu_m\left(j-0{,}5\right)\right)\right]^{-1} \qquad (21)$$

Note that expression (20) is obtained for the general case when not the outermost cable is damaged. For the damaged extreme (first) cable, expression (20) lacks an element $\cos\left(\mu_m\left(j-1{,}5\right)\right)$. In case of damage to the cable number *M*, the element is missing $\phi\cos\left(\mu_m\left(j+0{,}5\right)\right)$.

The coefficient *Q* is determined considering the difference in force distributions determined for the conditions of linear deformation and taking into account nonlinear deformation. The first components of the distribution of deformations and forces must be multiplied by it.

Finally, the calculation algorithm consists in determining the tension-deformed state of the rope under the conditions of linear deformation of the ropes using expressions (1)-(4), (9), 10, (12-(14), (16). Determine two unknown constant vectors from the conditions of connecting the ends of the rope to the structure or elements of the lifting machine. According to the determined distributions of forces in the ropes adjacent to the damaged one, choose the laws of force change. It should compensate for the excess of the calculated (linearly dependent) efforts over the actual ones, determined taking into account the differences in the values of the linear and non-linear modulus of elasticity. According to the defined laws, determine the coefficients of the Fourier series $C_{k,1}$, $C_{k,2}$. Substitute the values of the coefficients into expression (21). Find the value of the coefficient *Q*. Multiply by it the first components of the values of the internal load forces of the cables in expressions (19), (20) and displacements in expressions (1), (3). To obtain the desired displacements of the cables and the distribution of forces between them in a rope of a given design with a damaged arbitrary cable under the given conditions of connecting the ends of the rope.

Study of the stress-strain state of rubber-cable rope. Consider the main rope of a lifting machine with M cables and length L. We direct the x axis along the rope. Its beginning is in the cross-section of the connection to the machine element - to the pulley. The pulley is tilted at an angle ψ. The ropes are hinged to it at the cross-section $x = 0$. A load $x = L$ is attached to the other end. The cross-section of the rope, located normal to the deformation (load), remains normal to the axis of the rope and after the load [34].

We will formulate the boundary conditions for the adopted scheme

$$x = 0, \quad u_i = (i - 0{,}5)t\psi \quad \left(-\frac{M}{2} < i < \frac{M}{2}\right); \tag{22}$$

$$x = L, \quad u_i = 0, \tag{23}$$

where t – the pitch of the cables in the rope.

We write the boundary condition (22) in the form of a Fourier series

$$x = 0,\ u_i = \frac{2t\psi}{M}\sum_{j=1}^{M}(j - 0{,}5)\cos\left(\mu_m(j - 0{,}5)\right). \tag{24}$$

In the general case, the stressed-strained state of a flat rubber-cable rope is determined by the following dependencies [4, 5]

$$u_i = \sum_{m=1}^{M-1}\left(A_m e^{\beta_m x} + B_m e^{-\beta_m x}\right)\cos\left(\mu_m(i - 0{,}5)\right) + \frac{Px}{EFM}, \tag{25}$$

$$p_i = EF\sum_{m=1}^{M-1}\left(A_m e^{\beta_m x} - B_m e^{-\beta_m x}\right)\beta_m\cos\left(\mu_m(i - 0{,}5)\right) + \frac{P}{M}, \tag{26}$$

$$\tau_i = \frac{G}{h}\left(u_i - u_{i+1}\right), \tag{27}$$

where A_m, B_m - vectors of proportionality coefficients; P - rope load force; E, F - combined tensile stiffness and cross-sectional area of the cable; M - number of cables in the rope; $\mu_m = \frac{\pi m}{M}$; $\beta_m = \sqrt{\frac{2Gbk_G}{(t-d)EF}\left(1 - \cos\mu_m\right)}$; b – rope thickness; d, h - the diameter of the cable and the minimum distance between the adjacent cables of the rope; G, k_G shear modulus and a coefficient that takes into account the influence of the shape of the layer of elastic material located between the cables.

We use boundary conditions (23) and (24). Let's determine the values of the vectors of proportionality coefficients of expressions (25)-(27

$$B_m = \frac{2t\psi}{M\left(1 - B_m e^{-2\beta_m L}\right)} \sum_{j=1}^{M} (j-0{,}5)\cos\left(\mu_m (j-0{,}5)\right),$$

$$A_m = -B_m e^{-2\beta_m L}.$$

As an example, the stress state indicators of the GTK-3150 type rubber-cable rope with ten cables, 10 m and 5 m in length, were calculated under the condition $\psi = 0.01$ degree. The results are shown in Fig. 12.

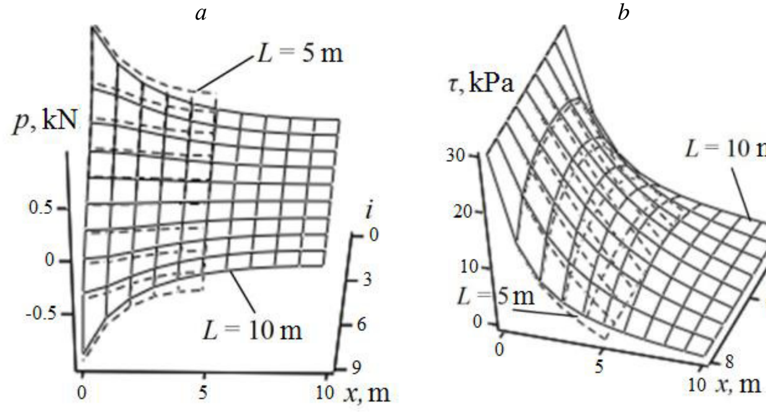

Fig. 12. Distribution graphs: *a* - internal forces *p* load of cables by numbers *i*; *b* - the maximum tangential stresses *τ* in the rubber layers along the axis of the rope *x* in the case of rotation of the pulley in the plane of the rope

In the absence of rotation of the end of the rope in the section $x = 0$ and rotation of the opposite end $x = L$, the coefficient vectors of expressions (4) – (6) are determined by the following dependencies

$$B_m = \frac{2t\psi}{M e^{\beta_m L}\left(e^{-2\beta_m L} - 1\right)} \sum_{j=1}^{M} (j-0{,}5)\cos\left(\mu_m (j-0{,}5)\right),$$

$$A_m = -B_m \, .$$

The results are asymmetric to the results of the previous case because the boundary conditions are asymmetric. At the same time, the linearity of the problem, the given forms of the solutions allow us to determine the stressed-but-strained state for the cases of the combination of different schemes of rotation of sections $x = 0$ and $x = L$. In the case of rotation of both edges, after removing asymmetric cases, we have two schemes. Let's look at them. For this purpose, we will add additional indices 0 and L to the designations of the angles of inclination of the specified sections, respectively. The coefficients will take on the following values

$$B_m = \frac{2t}{M}\left(\frac{\psi_L}{\left(1 - B_m e^{-2\beta_m L}\right)} + \frac{\psi_0}{e^{\beta_m L}\left(e^{-2\beta_m L} - 1\right)}\right) \cdot$$

$$\cdot \sum_{j=1}^{M} (j - 0{,}5)\cos\left(\mu_m (j - 0{,}5)\right),$$

$$A_m = -B_m\left(e^{-2\beta_m L} + 1\right) \cdot$$

Please note that the values of the angles must be substituted taking into account the sign of the direction of inclination.

For the conditions of the previous example, we considered the cases of equal rotation of both edges according to the absolute values of the angles in the same and opposite directions. The results of the calculations are shown in Fig. 13 and 14.

A comparison of the intervals of the maximum values of the internal load forces of the ropes and the maximum tangential stresses in the material of the rope sheath shows that turning the ends of the rope at equal angles does not affect their values.

Only the amplitude of the change of these values along the length of the rope decreases. The latter testifies to the effect of rope properties on the zone of manifestation of localization of disturbances.

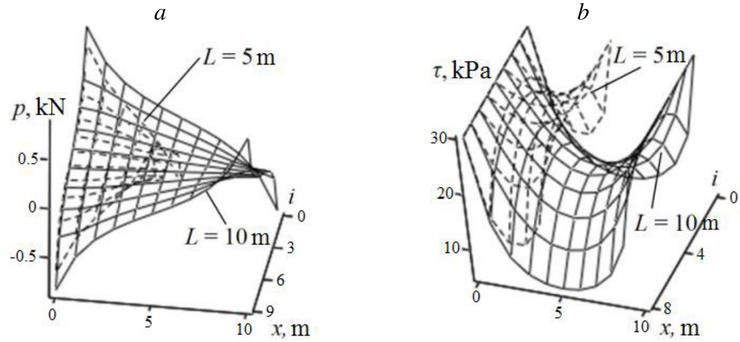

Fig. 13. Distribution graphs: *a* - internal forces *p* load of cables by numbers *i*; *b* - maximum tangential stresses *τ* in the rubber layers along the axis of the rope *x* in the case of equal turns of its ends

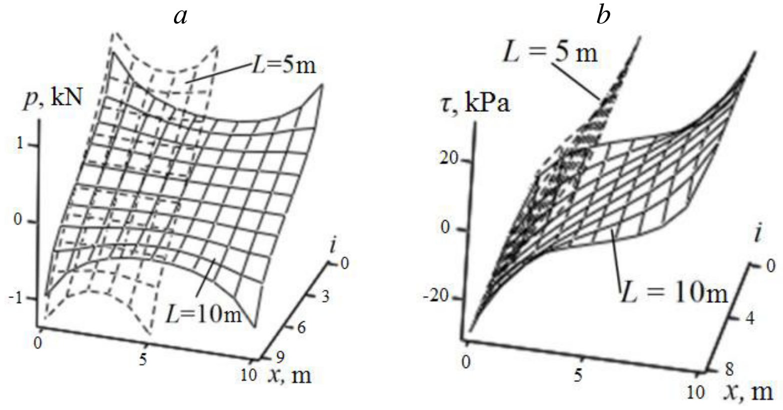

Fig. 14. Distribution graphs: *a* - internal forces *p* load of cables by numbers *i*; *b* - maximum tangential stresses *τ* in the rubber layers along the axis of the rope *x* in the case of opposite turns of its ends

A comparison of the dependencies (Fig. 13) and (Fig. 14) shows that turning the ends of the rope in opposite directions leads to an increase in the load forces of the cables by almost two times. Strength also increases with a decrease in the length of the rope. This is also a manifestation of overlapping zones of two disturbances. Due to the opposite rotation of the sections in the middle (longitudinal) part of the rope, tangential stresses are absent and do not depend on the length of the rope.

The indicated scheme of bends is the most dangerous from the point of view of rope strength. Considering equally possible turns in opposite directions of the cross-sections of connecting ropes, the strength condition must be ensured for the last case.

According to dependencies (25) – (27), the stress-strain state of the rubber rope along its own axis changes in proportion to the exponential functions $e^{\pm\beta_m x}$. The value of the vector β_m depends on the square root of the product of two parameters. The first one depends on the mechanical properties of the components of the rope and the geometric parameters of the cross-section of the elastic sheath located between adjacent cables. The second is the root of the cosine function of the number of ropes in the rope. The growth of each lead to a proportional increase in the lengths of the areas of manifestation of local disturbances. The first is proportional to the value $\sqrt{\frac{2Gbk_G}{(t-d)EF}}$. The second, as the performed analysis shows, is practically proportional to the three-fold increase in the number of cables in the rope.

Separately, we note that for ropes of considerable length, when the effects of marginal perturbations of stress states are not superimposed one by one, the following values of vectors of unknown coefficients can be used:

$$B_m = \frac{2t\psi}{M}\sum_{j=1}^{M}(j-0{,}5)\cos\left(\mu_m(j-0{,}5)\right),$$

$$A_m = 0.$$

Due to the absence of superposition of stress disturbances, the origin of the coordinate axis can be assumed to be in the cross-section of each end of the rope.

Extreme stress values are reached in the cross-sections of the rope connection ($x = 0$ or $x = L$) in the outermost cables and in the outermost layers of rubber. The known stresses make it possible to determine the admissibility of using the rope under the specified conditions.

Consider the case of rotation of the vessel around its own axis by an angle ψ. From the point of view of geometry, the axes of the centers of the cross-sections of the ropes of the section connecting the rope to the drum or to the vessel are located on passing straight lines. The latter are in planes normal to the axis of the rope. The angle between the projections of passing lines on the plane normal to the axis of the flat rope corresponds to the angle of rotation of the vessel relative to the drum ψ. The movement of the generator along the guide, located at a right angle to it, with its simultaneous rotation around the guide, forms a straight helicoid. Accordingly, provided the distance between the axes of the ropes remains unchanged, the flat rubber-cable rope takes the form of a straight helicoid. Ropes are in the form of spiral lines. At the same time, the centers of the cable sections remain on straight lines - the hypothesis of flat sections is fulfilled, but the cables have a constant length of the rope and a relative elongation that depends on the location in the rope. The indicated elongation is proportional to the distance of the rope from the axis of the rope and the angle of rotation of the vessel and is inversely proportional to the length of the rope. Absolute elongations related to the initial dimensions are relative elongations. Known elongations and Hooke's law make it possible to determine the distribution of forces between the cables.

Based on the above, we have the expressions of movements and distribution of forces in the cables of a flat rubber-cable rope connected to the elements of the machine, when the centers of the rope sections of the rope are located on passing straight lines.

$$u_i = \frac{P x}{E F M},$$

$$p_i = E F\left[\sqrt{\left(\left(\frac{M}{2} - i\right)\frac{t \psi \pi}{L}\right)^2 + 1} - 1\right] + \frac{P}{M}.$$

Objectively, the most heavily loaded are the outer ropes of the rope. There are no tangential stresses caused by the shift of the cables along the axis of the rope.

Supports for pylons.

It should be noted that the construction of pylons on the banks of the river bed can lead to landslides and collapses, and as a result, the destruction of the bridge. To prevent this, it is advisable to use retaining walls. Retaining walls are artificial structures designed to keep the mountain massif from collapsing. Retaining walls are divided by purpose, height, component material, angle of inclination of the back face, principle of operation, and also by the method of construction.

The retaining wall is subjected to various loads, including the wall's own weight, the pressure of the mining massif, the pressure of the weight of structures (supports, pylons) located on the supported massif, the pressure of construction equipment, and the pressure of water.

It is worth noting that riverbanks are the zone of action of groundwater. To prevent their negative impact on the wall at its base from the side of the mountain massif, a drainage system is usually built. However, this involves additional costs.

At the same time, there are walls of this design that do not require drainage systems. They consist of mesh gabion products (fig. 15).

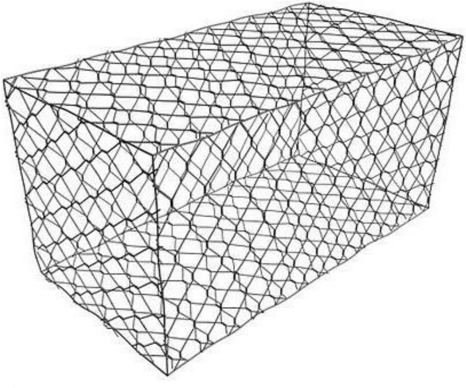

Fig. 15. 3×1×0,5 m Box-woven mesh gabion [36]

Gabions are metal containers of various shapes, consisting of a double-twisted metal mesh, which are filled with stone material. They are designed to create strong, flexible, and permeable massive supporting structures. The main types of gabions are mattress-tuff and box gabions. When erecting retaining walls on loose soils, gabions with a reinforcing panel are used. In recent years, gabions have gradually supplanted monolithic supporting structures, gaining in cost and quality [35].

The process of installing a retaining wall is as follows. The gabion is laid out on a hard flat surface, then walls and a diaphragm are attached to its bottom, which strengthen the structure. Then the walls and the diaphragm are connected in such a way as to obtain a capacity in the form of a parallelepiped.

After that, adjacent gabions relate to special stiffening membranes and reinforcing hooks are installed. Then formwork is installed along the length of the structure to prevent deformation of the gabions and filled with stone material, after which all operations are repeated.

Retaining walls made of mesh gabion products are used to hold soft rocks, fence highways and railway tracks, when erecting bridges and creating terraces on homesteads, as well as coastal fortifications of riverbeds. The construction of reinforced concrete structures requires a lot of labor and has a high cost.

In Ukraine, the production of gabions has been established, and there is also rich experience in the construction of engineering structures from them (fig. 16).

Fig. 16. Transport tunnel. Kyiv - Kharkiv – Dovzhanskyi [37]

Formation of an artificial island.

Damaged bridge supports must be converted into pylons. To increase the reliability and bearing capacity of the pylons, as well as to partially relieve the load on the cables, it is proposed to build artificial islands for wide rivers. For this, it is suggested to use a tower excavator [38-40].

At the beginning of the construction of the artificial bridge, overburden rocks are delivered to one of the banks of the river by dump trucks and stacked with a stable arrangement of the dump embankment, which is characterized by a minimum distance of rock transportation. On an undisturbed stable base, the drive support of the tower excavator is installed and at a safe distance from it, a receiving bunker is formed for the accumulation of overburden rocks. At the same time, the tail support of the same tower excavator is installed on an intact stable base near the opposite bank of the river. The supports of the tower excavator are connected by hanging, tail and traction ropes, which move the scraper (fig. 17.). These ropes are made of composite material and will be used as cables of this bridge in the future.

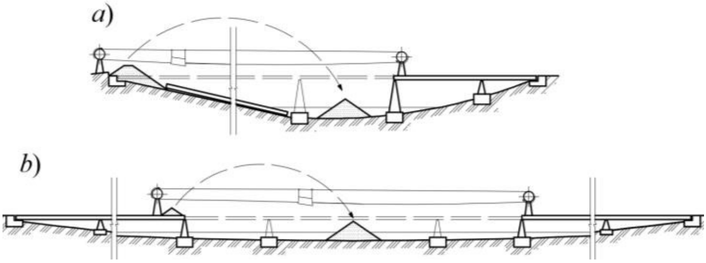

Fig. 17. Scheme of construction of an artificial island with a tower excavator: *a* – with the tower located on the riverbank, *b* – with the towers located on the not disturbed bridge sections

The delivery of rocks is carried out by plunging the bucket scraper under its own weight to the pile of rock in the receiving bunker and then moving it along the suspension rope to the place of unloading.

Alternatively, to reduce the length of the ropes, the supports of the tower excavator can be installed on the surviving bridge flights.

This solution allows you to quickly build an artificial island on a section of the river with an intense current, strengthen it with retaining walls, and then start building a pylon on it. The presence of an artificial island greatly simplifies and speeds up construction.

Conclusions.

The possibility of restoring bridges of Ukraine destroyed during military operations is shown. As an alternative to the restoration of destroyed bridges, it is proposed to install cable-stayed bridges. Well-known rubber-cable ropes, the production of which was established in Ukraine, were used as cable ropes. The reliability of the proposed ropes can be increased by increasing the number of ropes in them.

The existing experience in the construction of cable-stayed bridges, a wide raw material base, as well as the production of necessary materials allow us to assert the prospects of the direction of post-war reconstruction of destroyed bridges with the conversion of damaged supports into pylons. It is proposed to increase the reliability of the converted pylons and the bearing capacity of the bridge by strengthening the sides of the riverbanks with gabion retaining walls or by constructing an artificial island.

A model and algorithm for calculating the stress-strain state of a rubber-cable rope of arbitrary design, considering the nonlinear deformation of the ropes and the presence of a discontinuity of an arbitrarily located rope, has been developed. The model was built using the methods of the mechanics of composite materials. It is solved analytically in a closed form. The resulting algorithm can be considered sufficiently reliable and such that it allows you to reasonably determine the conditions for the safe use of rubber-cable ropes in case of damage to an arbitrary rope.

Analytical expressions are constructed in the work, which allow to determine the quantitative indicators of influence on the stress-deformed state of the rubber-cable rope of the turns of the cross-sections of its connection to the elements of the lifting machine and the rotation of the vessel around its longitudinal axis.

The equal inclination of the cross-sections connecting the ends of the rope in opposite directions compared to turning in one direction practically leads to a double increase in the load forces of the cables. The lengths of the areas of manifestation of local disturbances depend on the square root of the product of two parameters. The first depends on the mechanical properties of the components of the rope and the geometric cross-section parameters of the elastic sheath located between adjacent cables. The second is the root of the cosine function of the number of cables in the rope. The growth of each lead to a proportional increase in the lengths of the areas of manifestation of local disturbances. At the same time, the increase is proportional to the threefold increase in the number of ropes in the rope. Extreme stress values are reached in the cross-sections of the rope connection in the outermost ropes and in the outermost layers of rubber. The rotation of the vessel around the longitudinal axis of the rope is accompanied by the acquisition of the shape of the surface of a straight helicoid by the rope, and helical lines by the cables. The radii of the helical lines are proportional to the distances to the cables from the rope axis.

References

1. **Shvaher, N., Komisarenko, T., Chukharev, S., & Panova, S.** (2019). Annual production enhancement at deep mining. E3S Web of Conferences, 123, 01043. https://doi.org/10.1051/e3sconf/201912301043
2. **Babets, Y., Anisimov, O., Shustov, O., Komirna, V., & Melnikova, I.** (2021). Determination of economically viable option of liquidation the consequences of external dump deformation. E3S Web of Conferences, 280, 08014. https://doi.org/10.1051/e3sconf/202128008014
3. **Pysmennyi, S., Fedko, M., Shvaher, N., & Chukharev, S.** (2020). Mining of rich iron ore deposits of complex structure under the conditions of rock pressure development. E3S Web of Conferences, 201, 01022. https://doi.org/10.1051/e3sconf/202020101022
4. Naibilsha kilkist zruinovanykh mostiv - na Chernihivshchyni (January 2, 2023). Chas Chernihivskyi https://cntime.cn.ua/najbilsha-kilkist-zrujnovanih-mostiv-na-chernigivs-article/
5. Na zruinovanii rosiianamy perepravi cherez inhulets zavershuiutsia remontni roboty (December 22, 2022). Ukrainskyi pivden. Informatsiine vydannia https://pivdenukraine.com.ua/2022/12/22/na-zrujnovanij-rosiyanami-perepravi-cherez-ingulec-zavershuyutsya-remontni-roboti/
6. V Iziumi vidnovyly zruinovanyi pid chas okupatsii mist (November 3, 2022). Suspilne novyny https://suspilne.media/309272-v-izumi-vidnovili-zrujnovanij-pid-cas-okupacii-mist/
7. **Komarov, D.** (2023). RIK – avtorskyi dokumentalnyi proiekt Dmytra Komarova | Chastyna persha. www.youtube.com/watch?v=EhssmUtN874
8. Darivskyi mist na Khersonshchyni mozhna vidnovyty za 1-3 misiatsi (November 13, 2022) Suspilne novyny https://suspilne.media/315840-darivskij-mist-na-hersonsini-mozna-vidnoviti-za-1-3-misaci/
9. **Komarov, D.** (2023). RIK – avtorskyi dokumentalnyi proiekt Dmytra Komarova | Chastyna druha. https://www.youtube.com/watch?v=rlkzADUfb3s
10. **Khrystoforov, V.** (September 27, 2011). U Kremenchutsi montuiut novyi betonnyi zavod dlia budivnytstva mostu cherez Dnipro. Promyslovyi portal. Sait #1 pro rozvytok ta promyslovist Ukrainy https://uprom.info/news/other/buduvannya/u-kremenchuczi-montuyut-novyj-betonnyj-zavod-dlya-budivnycztva-mostu-cherez-dnipro/

11. **Volokhovskiy, V.Yu., Radin, V.P., & Rudyak, M.B.** (2010). Kontsentratsiya usiliy v trosakh i nesushchaya sposobnost rezinotrosovykh konveyernykh lent s povrezhdeniyami. Vestnik MEI, (5), 5-12.

12. **Belmas, I.V.** (1993). Napryazhennoe sostoyanie rezinotrosovoy lenty pri proizvolnom povrezhdenii trosov. Problemy prochnosti i nadezhnosti mashin, (6), 45-48.

13. **Belmas, I.V., Kolosov, D.L., Tantsura, A.I., & Konokh, Yu.V.** (2009). Issledovanie vliyaniya poryva trosovoy osnovy na prochnost kanata stupenchatoy konstruktsii. Neobratimye protsessy v prirode i tekhnike: Materialy nauch. konf. Moskva: MGTU im. N.E. Baumana, 2, 255-257.

14. **Belmas I.V., & Bobylova I.T.** (2012) Vplyv poryviv trosiv na mitsnist ploskoho tiahovoho orhanu. Recueil des exposes des participants de VI Conference internationale scientifigue et methodigeue, 88-91.

15. **Kolosov, L.V., & Belmas, I.V.** (1990). Issledovanie prochnostnykh kharakteristik obraztsov povrezhdennykh rezinotrosovykh lent. Izvestiya vuzov. Gornyy zhurnal, (8), 81-84.

16. **Kolosov, L.V., & Belmas, I.V.** (1991). Eksperimentalnye issledovaniya agregatnoy prochnosti RTL. Izvestiya vuzov. Gornyy zhurnal, (1), 85-87.

17. **Ropay, V.A.** (2016) Shakhtnye uravnoveshivayushchie kanaty: monografiya. Natsionalnyy gornyy universitet.

18. **Belmas, I., & Kolosov, D.** (2011). The stress-strain state of the stepped rubber-rope cable in bobbin of winding. Technical and Geoinformational Systems in Mining, 211-214. https://doi.org/10.1201/b11586-35

19**. Belmas, I., Kolosov, D., Bilous, O., & Onyshchenko, S.** (2018). Stress-strain state of a conveyor belt with cables of different rigidity and their breakages. Fundamental and applied researches in practice of leading scientific schools, 26(2), 231–238.

20. **Belmas, I., Kolosov, D., Chechel, T., Vorobiova, O., & Chernysh, O.** (2020). Influence of change during the mechanical properties of rubber on the stressed state of a rubber traction body with a damaged cable. Collection of Research Papers of the National Mining University, 62, 149–155.https://doi.org/10.33271/crpnmu/62.149

21. **Kolosov, D.L., Bilous, O.I., & Hurov, I.A.** (2019). Mitsnist vidnovlenoi humotrosovoi strichky. Matematychni problemy tekhnichnoi mekhaniky ta prykladnoi matematyky. Materialy mizhnarodnoi naukovoi konferentsii, 126-127.

22. **Belmas, I., Kolosov, D., Onyshchenko, S., & Bobylova, I. (**2020). Partial restoration of tractive ability of rubber-cable tractive element with damaged cable base. Collection of Research Papers of the National Mining University, 60, 196–206. https://doi.org/10.33271/crpnmu/60.196

23. **Belmas, I.V., Bilous, O.I., Tantsura, H.I., & Bobylova, I.T.** (2018). Zirochka. (Patent № 117954)

24. **Belmas, I.V., Kolosov, D.L., Bilous, O.I., & Bobylova, I.T.** (2019). Doslidzhennia napruzhenoho stanu hnuchkoho tiahovoho orhanu z kinematychnym zv'iazkom. Zbirnyk naukovykh prats VIII Mizhnarodnoi naukovo-tekhnichnoi konferentsii «Prohresyvni tekhnolohii v mashynobuduvanni RTME 2019», 72-73.

25. **Kolosov, L.V., & Belmas, I.V.** (1990). Analiz skhem stykovykh soedineniy rezinotrosovykh lent. Izvestiya vuzov. Gornyy zhurnal, (2), 83-85.

26. **Levchenya, Zh.B.** (2004). Povyshenie nadezhnosti stykovykh soedineniy konveyernykh lent na gornodobyvayushchikh predpriyatiyakh: Na primere RUP "PO "Belaruskaliy" (dissertatsiya ... kandidata tekhnicheskikh nauk: 05.05.06).

27. **Tantsura, H.I**. (2010). Hnuchki tiahovi orhany v mashynobuduvanni. Stykovi ziednannia konveiernykh strichok: monohrafiia. DDTU.

28. **Zabolotnyi, K., Panchenko, O., Zhupiiev, O., & Polushyna, M.** (2018). Influence of parameters of a rubber-rope cable on the torsional stiffness of the body of the winding. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, (5), 54-63. https://doi.org/10.29202/nvngu/2018-5/11

29. **Belmas, I. V., Kolosov, D. L., Bilous, O. I., Tantsura, G. I., & Gupalo, U. U**. (2020). Influence of defect of connection of a cable rope on its intense condition. Collection of Scholarly Papers of Dniprovsk State Technical University (Technical Sciences), 101–106.https://doi.org/10.31319/2519-2884.tm.2020.20

30. **Belmas, I., Kolosov, D., Dolgov, O., Chechel, T., & Vorobiova, O.** (2021). Stress-strain state of flexible composite tractive element of irregular structure. Collection of Research Papers of the National Mining University, 66, 116–124. https://doi.org/10.33271/crpnmu/66.116

31. **Kolosov, D., Samusia, V., Tantsura, H., Bilous, O., & Vorobiova, O.** (2021). Influence of deformation non-linearity of cables on rope stressed-strain state. Collection of Research Papers of the National Mining University, 66, 132–139. https://doi.org/10.33271/crpnmu/66.132

32. **Hupalo, Y., Belmas, I., Belous, O., & Tantsuna, A.** (2022). Algorithm for determining permissible deviations of cable rope connection nodes to structure. Technical Sciences and Technologies, 1(27), 67–73. https://doi.org/10.25140/2411-5363-2022-1(27)-67-73

33. **Belmas, I., Kolosov, D., Onyshchenko, S., Bilous, O., Tantsura, H., & Chernysh, P.** (2022). Stress-strain state of composite rope considering influence of its nonlinear deformation and reinforcement element breakage. Collection of Research Papers of the National Mining University, 70, 99–106. https://doi.org/10.33271/crpnmu/70.099

34. **Belmas, I., Kolosov, D., Dolgov, O., Onyshchenko, S., Tantsura, H., & Bilous, O.** (2022). Influence analysis of hoisting machine vessel turning on stress state of head rubber-cable rope. Collection of Research Papers of the National Mining University, 70, 91–98. https://doi.org/10.33271/crpnmu/70.091

35. **Adamchuk, A.A.** (2017). Research of finalizing parameters of deep open-cast mines. Collection of Research Papers of the National Mining University, 50, 10–17.

36. Habion korobchatyi pletenyi 3kh1kh0,5m, vichko 80kh100mm (n.d.). Kamin Lviv Bud https://stonelvivbuild.com.ua/ua/p1656407315-gabion-korobchatij-pletenij.html

37. Nashi roboty (n.d.). ViaCon http://viacon.ua/gallery.html

38 **Dryzhenko, A. Yu., Nikiforova, N.A., Ropai, V.A. & Babets Ye.K.** (2016). Sposib zasypky vidroblenoho hlybokoho kar'ieru (Patent No. 111289).

39. **Dryzhenko, A. Yu.** (2011). Kar'ierni tekhnolohichni hirnychotransportni systemy. NHU.

40. **Dryzhenko, A. Yu.** (2014). Vidkryti hirnychi roboty: pidruchnyk. NHU.