SUMMARY

Of thesis MOLDAGOZHINA M.K.

"Development of a combined flexible support with adjustable bearing capacity" prepared for receiving the degree of PhD in the specialty

6D070700- "Mining"

The relevance of the research topic. Increasing the efficiency of underground mining of deposits of solid minerals by underground, improving the conditions of mining operations, rational use of mineral resources is impossible without fixing the mine workings. Maintenance-free maintenance of mine workings can be achieved due to the correct scientifically substantiated choice of the type of support and its parameters.

In the complicated mining and technical conditions, it is necessary to consider the anchor and the sprinkling reinforcement, which are characterized by a high degree of mechanization of their erection. There are a large number of varieties of anchors, designed taking into account the variety of mining conditions of deposits.

However, an analysis of the experience of erecting and operating an anchor support shows that the reasons for the reliability of maintaining mine workings are the shortcomings in the technology of installing anchors and the inconsistency of the support to the mining technical conditions of the deposits because of unreliable information about the operation of the anchor support system. The shortcomings and shortcomings of technologies allowed directly during the installation of anchors, although they are removable, but difficult to control, and errors and miscalculations resulting from insufficient information on the actual work of the anchor support, are much more difficult to eliminate.

For the erection of the sprayed concrete support, a number of machines are used, which use compressed air for spraying the mixture. These units have a number of significant drawbacks that reduce the efficiency of the erection of the support. Among them, the main is the high rebound of the material, the air involved in the mixture, which worsens the hardening conditions of the mixture and a number of others. A promising way to eliminate these drawbacks is the use of centrifugal force to apply the shotcream mixture. Such installations allow the application of a layer of spattered concrete of increased thickness in one pass and thereby create the preconditions for obtaining a safe concrete support with all its advantages.

However, the technology and mechanization of this method of erecting the spiked support are insufficiently studied, which does not allow expanding the scope of its use.

The most promising is the construction of a flexible support, which combines an anchor and a sprinkling support.

Many studies have been devoted to the investigation of the technology and mechanization of the erection of anchor and spattered concrete support. However, a number of issues related to the work of the "anchor support system - fixed mountain massif" system and machines using the new method for applying the shotcrete

mixture-centrifugal force to mount the mine workings have not been fully investigated, which predetermined the relevance of the present studies.

The purpose of this work is to improve the reliability of fastening the mine workings by creating a compliant combined support, which includes the joint work of the anchor and the sprinkling reinforcement.

The main idea of the work is to control the bearing capacity of the combined support by matching the modes of its erection to the mining technical conditions of the deposit.

During the work, a complex research method was used, including analysis and scientific generalization of scientific and technical information, theoretical and laboratory studies, physical and computer modeling of research objects, methods of mathematical statistics for processing results.

Scientific provisions and results to be protected

- combined compliant fasteners, provides effective interaction with host rocks due to a step-by-step perception of rock displacements: in the initial period of intensive rock displacements, tubular hydro-transport anchors with a given bearing capacity work, and at the end of this period, the rock pressure is also perceived by an arch constructed from dropping-concrete crepe.

- the main factor ensuring the load-bearing capacity of the hydro-dispersed tubular anchors is their uniform distribution in the hole during installation, which is ensured by the manufacturing technology and installation parameters;

- the power characteristics of the anchor support are determined by the completeness of contact between the anchor surface and the rock being fixed, its strength and fracturing, the length of the anchor part of the anchor, and the setting pressure of the liquid;

- the stress-strain state of the elements and units of the centrifugal shotcrete machine, depending on the load on them and the characteristics of the materials from which they are made, can be described by differential equations taking into account the coefficients of the object and the magnitude of the external forces

Scientific novelty consists in the following:

- The main provisions for the operation of the system "Hydraulic Tubular Anchor - Fixed Rock Massif" are established;

- the calculated dependences of the bearing capacity of the hydro-transport tubular anchors on the water setting pressure, the borehole diameter and the pipe from which the anchor is made, the length of the lock part, the coefficient of friction between the anchor and the rock are established:

- A method has been developed for determining the load-bearing capacity of hydro-transport tubular anchors and an analytical formula has been proposed for its implementation;

- a technique for studying the stress-strain state of the supercharger elements of a centrifugal shot crete machine and the work of combined flexible support on the basis of a block-hierarchical approach;

The validity and reliability of the scientific provisions, the results of the input shafts and recommendations is based on the use of proven methods and methods of research, the method of computer modeling, the evaluation of the obtained

dependences by methods of mathematical statistics with sufficiently high indicators and satisfactory convergence of the results of theoretical and experimental studies.

The practical significance of the work is as follows:

- a methodology has been developed for calculating and predicting the load-bearing capacity of tubular hydraulic-lifting anchors for securing workings with an anchor length of 2 to 4 m;

- Modifications of hydro-transport tubular anchors are proposed taking into account the characteristics of the rock being fixed and the means for their installation;

- The technique of engineering calculation of the main units of a centrifugal shotcrete machine has been developed;

- a technique for computer simulation of the stress-strain state of nodes and elements of a centrifugal shotcrete machine and a combined flexible support is proposed.

Scientific significance of the work

The proposed construction of a compliant combined support on the basis of strengthening the rock mass with hydraulically-dispersed tubular anchors in combination with a sprayed concrete supports significantly improves the characteristics of the support and the degree of mechanization of its erection.

Realization of the results of work

The results of theoretical and experimental research on the thesis are included in lecture and practical classes in the disciplines "Mining machines" (bachelor degree in specialty 5B072400) and "Innovative technology and technology in the mining and metallurgical industry" (magistracy 6M071200- for GPIIIR-2).

Approbation of work

The results of the research on the thesis were reported and approved at international scientific and practical conferences: in the Magnitogorsk State Technical University named after G.I. Nosov at the International Technical Conference "Theory and practice of mining, processing and application of natural stone", Zhezkazgan University named after A.O. Baikonurov at the International XV Baikonur Readings, at the XIV International Conference in Munich (Germany) "European Science and Technology" and at the International Conference in Moscow "Miner's Week", scientific and technical seminar of the department "Technological Machines and Equipment" KazNTU named after K.I. Satpayev.

Publications

According to the results of the research, 8 published works were published, including 1 article in the journal included in the database "SCOPUS", 1 report in the far abroad, 2 reports in the near abroad, 2 articles in publications recommended by the CCSS MES RK, 2 reports at international conferences.

Structure and amount of work. The thesis consists of an introduction, 4 chapters and conclusions, outlined on 125 pages of typewritten text, including 84 figures, 25 tables and bibliographies from 56 sources.

The main content of the work

The work of many domestic and foreign scientists, such as Sh. M., is devoted to the research of technology and mechanization of anchor and spattered concrete support. Aitaliyev, B.I. Iskakov, P. Shilkin, V.N. Semevsky, A.A. Borisov, E.Ya. Makhno, A.P. Shirokov, A.T. Tallbor, A. Costa, A. Johnston and several others.

However, a number of issues related to the work of the "anchor anchorage-anchored array" system and machines for the construction of flexible supports have not been fully investigated, which predetermined the relevance of these studies.

There is an international methodology for selecting fastenings for mining and capital works and preparatory workings on the basis of the Q-rating. Q-system is the quality index of tunnels, developed at the Norwegian Geotechnical Institute by Barton in 1974 (Fig. 1). according to this diagram in rocks of 3-7 categories of rock mass stability it is recommended to use systematic anchoring in combination with spattering concrete for fastening of mine workings.

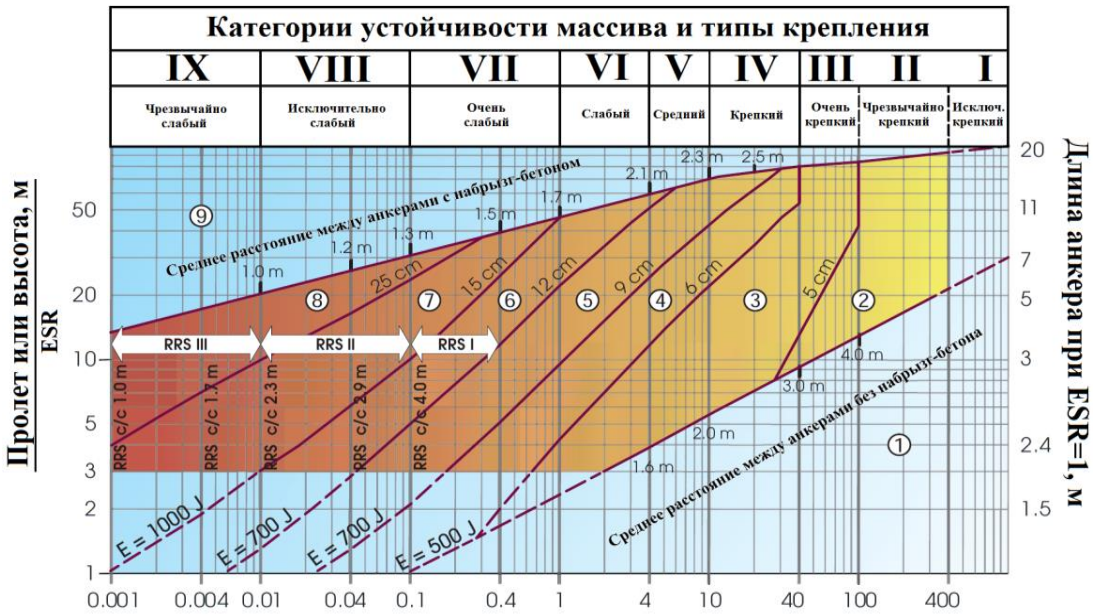


Figure 1. - Diagram of the type and parameters of the support depending on the Q-rating.

The analysis of the literature sources and practices of mining enterprises both in our country and abroad showed that the most promising ones are the abrasive concrete support and the anchorage.

The main advantage of such supports is the ability to maintain efficiency with significant offsets of the rock mass contour, fast erection of the support, high load-bearing capacity, wide range of use in various mining conditions.

At the present time, anchors of various designs have spread in the mining industry: reinforced concrete rod support, steel-polymer, fiberglass anchors, anchor friction support, hydraulic anchor support, anchor cable fastening and a number of others. To install the anchorage, anchor installers are widely used with 100% mechanization of this process.

Great progress has been made in the spray-concrete support, where there are a number of machines that apply a dry and wet shotcrete mixture to the walls of the mine workings with the help of compressed air.

However, these supports are rigid and practically do not allow compliance, which is necessary for effective control of the state of the rock massif. Therefore, it is necessary to develop a flexible support that eliminates the noted shortcomings.

The analysis made it possible to propose a combined support from hydraulically-driven anchors working in conjunction with a spray-on concrete support (Fig. 2).

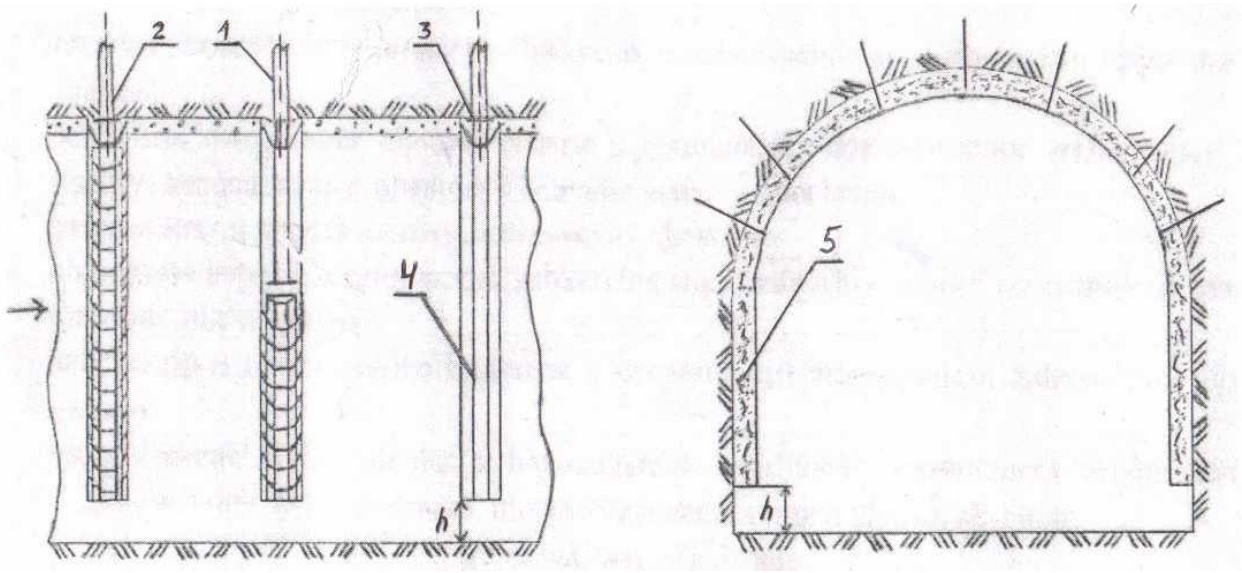


Fig.2 - Production scheme with combined flexible masonry

1- support washer, 2-tubular anchor, 3-end, 4 reinforced-concrete arch fasteners, 5 nabryzgbebiton;

Such fasteners with adjustable compliance can be created, thanks to the tubular hydro-transport anchors developed in Kazakhstan and the machine for the centrifugal shotcrete of MCT. The erection of such a support is carried out in the following order. Mounted tubular goadroyspornye anchors (TGA), they are attached to the desired configuration of the fittings, which the machine MCT is applied shotcrete, creating a theme the most reinforced concrete arch. At the same time, the arch does not reach the working soil at a distance (h) equal to the magnitude of the intensive displacement of the rocks.

In the period of intensive rock shifting, only TGAs with the given bearing capacity work, and by the end of this period the reinforced concrete arch suspended to the TGA rests against the soil of development and is then included in the work, taking over part of the load. It retains production from destruction, and TGAs continue their work.

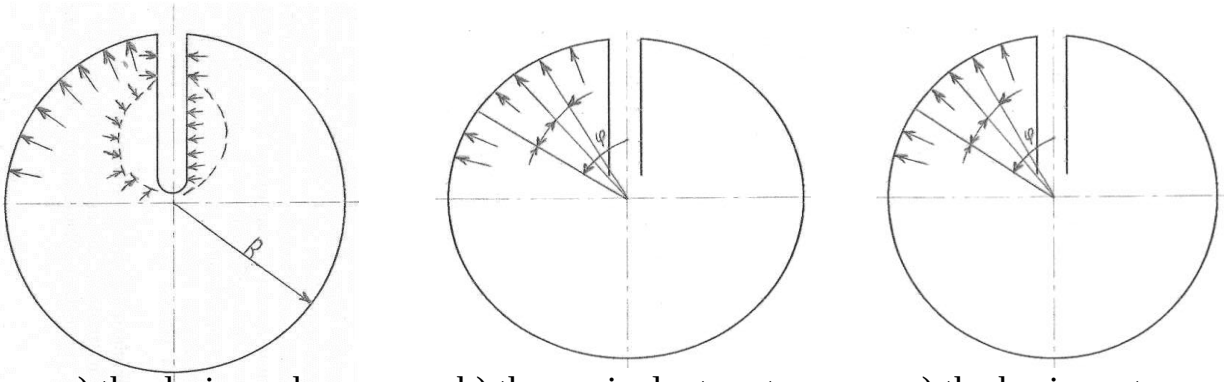
To implement such a crepe it was necessary to solve a number of problems:

- to develop and justify a fundamentally new scheme of combined flexible support;
- to investigate the operation of the "anchor-anchored rock massif" system and the construction of the hydro-anchor anchor;

- to apply a high-quality shotcrete mixture to investigate the operation of a new centrifugal shotcrete machine;
- develop a methodology for calculating the hydro-transported tubular anchors;
- to investigate the work of the proposed combined flexible support by computer modeling.

To ensure the effective work of the anchorage, it is necessary to clearly represent the mechanism for fixing rocks. To this end, the operation of the "tubular hydro-transport anchor-fixed rock system" system was investigated. As already mentioned earlier, the original composite anchor construction, developed by Massaget JSC, is used in the proposed combined flexible support.

To develop a methodology for calculating the steady operation of such anchors in conjunction with fixed rocks, a model of this process is proposed in the dissertation (Fig. 3).



a) the design scheme b) the equivalent system c) the basic system

Fig.3 - Calculation scheme of the operation of the hydro-dissipated tubular anchor

Anchor section is a symmetrical closed contour of complex outline, loaded with a symmetric evenly distributed load. To simplify the calculations, we replace the teardrop, compensating loop in the section of the anchor with rectilinear radial distributed sections loaded with distributed loads. Considering the plane problem, one can obtain a solution for an anchor ring with a length of the generator equal to "in". The design scheme is a three-fold statically indeterminate frame. Solving this problem it is established that when plastic deformations occur, the stresses become equal to the yield point, and the pressure of the liquid at which the plastic deformations begin to develop is determined by the expression

$$P_{\text{тек}} \geq \frac{\delta_{\text{T}} \cdot t^2}{5{,}5 \cdot R^2}, \qquad (1)$$

where δ_T is the yield strength of the anchor material;

t- wall thickness of the anchor;

R is the radius of the cylindrical part of the workpiece of the anchor;

In the dissertation conditions of joint work of the anchor and the fixed rock after the "opening" of the pipe are considered (Fig. 4). It was assumed that:

- the inner pipe is an anchor, loaded from the inside by the pressure of the working fluid;
- a rock mass with a hole is an outer pipe with an infinitely large wall thickness.

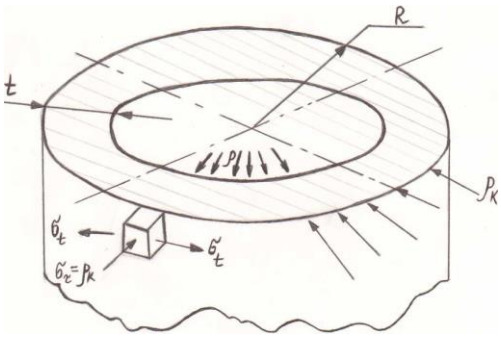


Fig.4 a Stress state of the anchor pipe

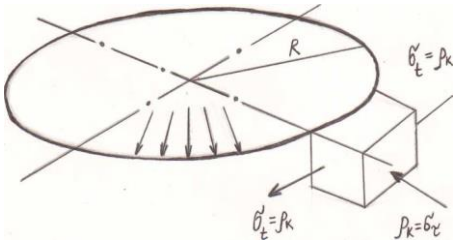


Fig. 4 b - Stress state of the hole wall

The solution of this problem made it possible to obtain a design formula for the rational pressure of a liquid in the cavity of a pipe and the resulting frictional forces

$$P = \frac{\delta_t}{\frac{R}{t}\left[1-\frac{\frac{R}{t}-1/E_c}{\frac{(1+\mu_п)}{E_п}+\left(\frac{R}{t}-\mu_c\right)/E_c}\right]} \qquad (2)$$

where δ_t are the circumferential normal stresses;
E_c is the modulus of elasticity of steel;
μ is the Poisson's ratio.

The analysis of the force conditions for the interaction of the anchor with the rock makes it possible to determine the necessary length of the anchor from the condition that the pipe does not penetrate through the wall of the hole. This condition is fulfilled until the axial load on the anchor is less than the friction forces F, which are determined by the formula:

$$F = f P_k \pi d_{ш} \cdot l_3 \text{ , H,} \qquad (3)$$

where f is the sliding friction coefficient of the steel by the rock; P_k- pressure on the contact surface of the pipe with the wall of the hole, l_3- length of the anchor part, located in the basic undisturbed rocks (lock part); d_ш- diameter of the hole under the anchor.

Thus, the dependence of the stability of the tubular hydro-dissipating anchor on the main influencing factors is established in the operation of the "anchor-anchored mountain range" system.

The carried out researches testify that of the whole set of mining and geological and production factors that can influence the power characteristics of anchors with locking fastening with short-term loads, the following are determining: the construction of the anchor lock, the displacement relative to the hole, the strength and fracturing of the rocks at the place of securing the lock , parameters and shape of the holes and water cut of the rocks.

The main drawback inherent in most proposed calculation methods are the assumptions caused by insufficient knowledge of the mechanism of interaction of the support with rocks at the anchor contact with the surface of the hole.

The bearing capacity of anchors working on tension is determined by the strength of the fastening or the explosive force of the rod and is taken in calculating the operational parameters of the support of the mine workings at the lowest value.

One of the important characteristics of the anchor support is its bearing capacity. The conducted researches made it possible to propose a non-destructive method for determining the load-bearing capacity of anchor fastening, for which the formula

$$F_{\text{г.а.}} = k\mu\pi d_{\text{ш}} l_{\text{з}} P f_{\text{тр}},\ \text{Н}, \qquad (4)$$

Where $k = \frac{d_{\text{ш}}}{d_{\text{тр}}}$ - coefficient that takes into account the completeness of contact between the surfaces of the anchor and the hole (here d_ш and d_тр are, respectively, the diameters of the hole and the pipe from which the anchor is made), m; μ is the Poisson's ratio (for steel μ = 0.24 ÷ 0.28); l_з- length of the anchor part of the anchor, m; P- pressure of liquid inside the anchor (setting pressure), Pa.

Depending on the pressure of the liquid inside the anchor, not the pressure P_k on the contact surface of the pipe with the wall of the hole, as provided in the formula. This is due to the fact that it is practically impossible to determine the value of P_k with a high degree of reliability, while the fluid setting pressure is a stable and definite value. Moreover, taking into account that in practice the pipe of the profiled anchor is not fully disclosed, the value of the bearing capacity of the anchor must be determined by taking into account the correction by introducing a coefficient k taking into account the completeness of contact between the surfaces of the anchor and the hole.

The presented dependence correlates well with the dependence obtained as a result of the theoretical studies presented in this dissertation.

The reliability of this formula is confirmed by the results of experimental studies in laboratory conditions.

Figure 5 shows the results of experiments to determine the strength of the extraction of an anchor

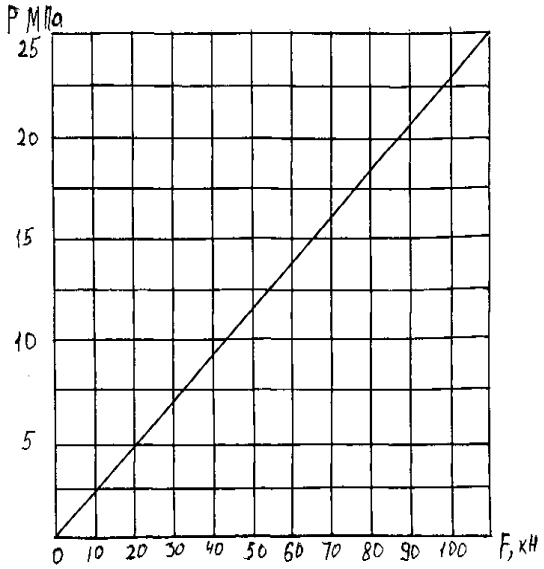


Fig.5 - Dependence of the anchor extraction force on the pressure of the expansion fluid in various media

The results of the experiments on establishing the relationship between the bearing capacity of the anchor and the pressure of the fluid expansion for different rocks were processed by mathematical statistics using the standard program. It is established that this relationship is described by the regression equation of the form

$$F_{aH} = A + B \cdot P + C \cdot P^2, \text{ H}, \quad (5)$$

$$5{,}0 < P < 35{,}0, \text{ МПа}$$

where F_aH is the force of extracting the anchor from the hole, H; P- pressure in the device, Pa; A, B, and C are empirical coefficients, depending on the characteristics of the anchored rocks and the anchor part of the anchor.

Based on the results of the studies, advanced designs of hydro-transport tubular anchors and the technology of erection of anchor support are proposed.

The second moment in the construction of the proposed combined flexible support is the erection of a concrete belt with a thickness of 250-300 mm, working together with tubular hydro-transport anchors. For this purpose, it is proposed to use a fundamentally new design of the machine for erecting a spray-concrete fastener MCT 12, developed by JSC "Massaget". This machine, in contrast to the existing ones, which use compressed air for spraying-concrete mix, uses the centrifugal force of the mixture to escape from the special supercharger.

Existing calculation methods in full are not applicable to the calculation of the ITC machine, because they have different principles of operation. In connection with this, one of the tasks of this study was the development of a methodology for calculating the main elements of the MCT-12 machine and modeling the stress-strain state of its main nodes during operation.

Based on the results of the research, formulas are recommended before calculation

- productivity of screw feeder;
- stresses in supporting bearings;

- drive power;
- static stability of the machine.

According to the proposed method, verification calculations of the main parts of the machine were made and recommendations for their improvement were given.

To obtain information on the stress-strain state of the nodes of the MCT-12 machine, the simulation of their work using the ANSYS software was performed. The shaft of a centrifugal supercharger, as the most loaded unit, as well as the impeller blades subjected to the greatest abrasive wear from friction when the sprayed concrete mix was moving along it were subjected to research.

According to the results of computer simulation, pictures of equivalent stresses along the shaft and blades of the impeller, as well as graphs of the absolute value of the equivalent load, are obtained. Their analysis allows
to present a real picture of the stress-strain state of the elements under investigation (Figs. 6 and 7).

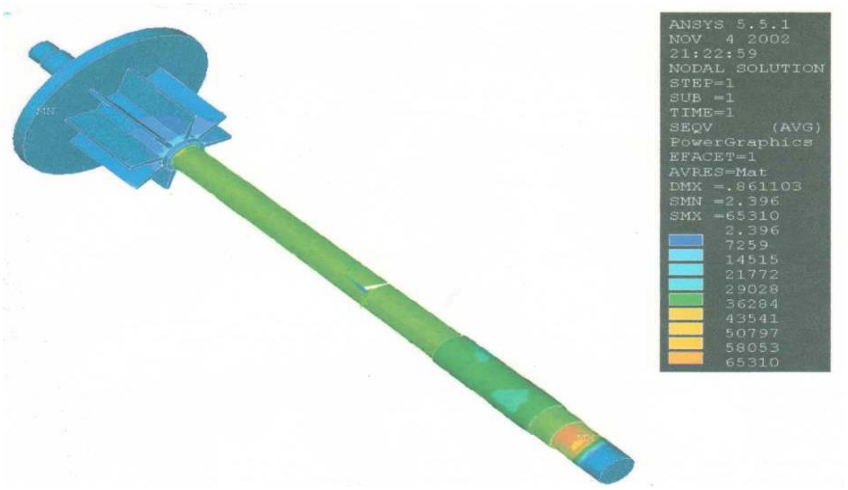


Figure 6 - Equivalent stress distribution

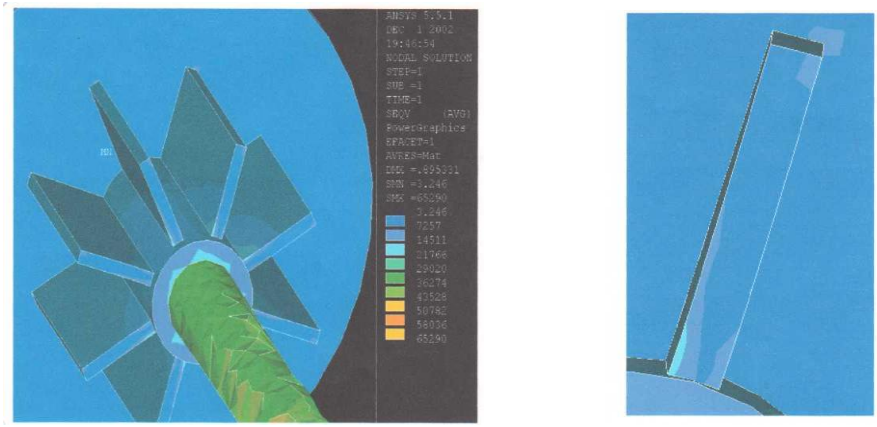


Figure 7 - Equivalent stress distribution

From the equivalent load distribution diagrams, it is seen that the region of the impeller blades of interest to us is loaded as follows: the node 7 is most loaded from the side to the opposite side of the loaded shotcrete mixture at the base of the blade. Also, there is an increase in the load at the edge of the top of the blade from the side loaded with the shotcrete mixture. To obtain a more detailed picture of the

distribution of the equivalent load in the directions of interest to us, graphs of the stresses in the investigated region are plotted against the length of an arbitrarily chosen contour.

The results of computer modeling allowed us to recommend a modernized configuration of the impeller blade with the most rational cross section, and also to recommend a method for calculating ITC elements based on the weighted average of the loads, and places with peak Load values should be checked for permissible overload in accordance with existing design standards.

In order to obtain a picture of the work proposed by the combined flexible support with adjustable bearing capacity, computer simulations were carried out using the Autodesk inventor program.

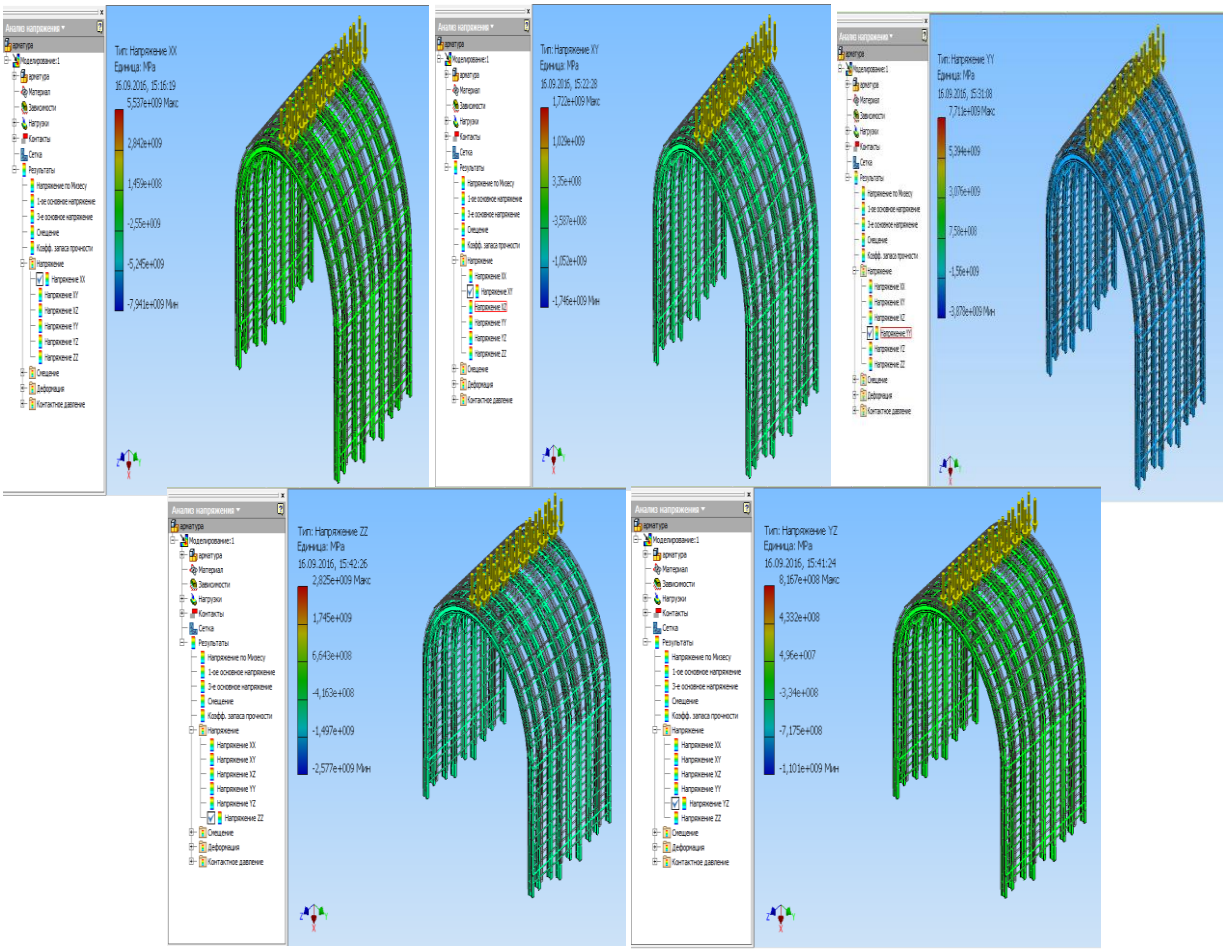
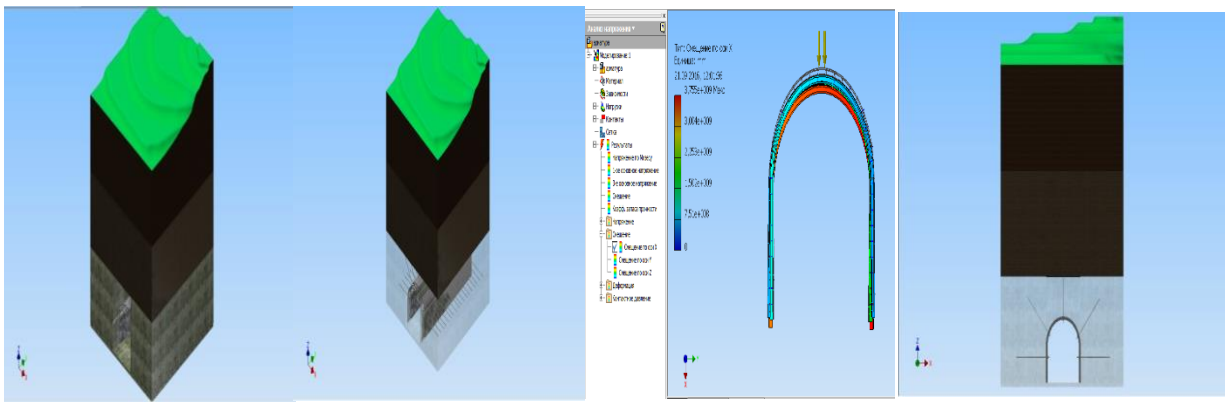


Fig. 8 - stresses in the combined flexible support



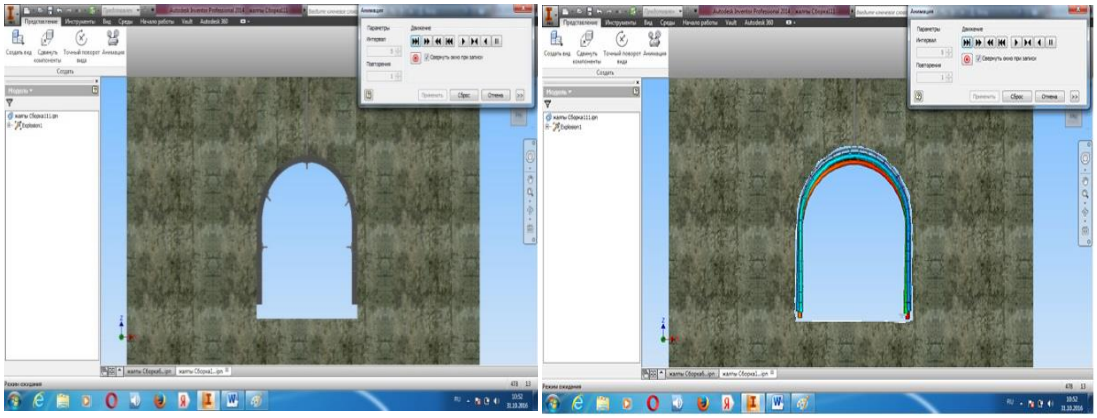


Fig. 9 - Deformations of the combined flexible support from the effects of external forces.

The simulation results are shown in Figures 8 and 9.

Analysis of the modeling results of the proposed support showed that depending on the external load, when the load is reached, the components of the support are losing their efficiency. Analytic calculations based on kinematic schemes do not take into account the influence of some parameters on the structural elements of the support, although they can have a significant effect on the safe work of the support. Because to take into account the influence of these factors, along with analytical calculations, it is necessary to take into account the results of modeling.

The analysis showed that the following forces act on the supports:

- the force of the rock pressure from the enclosing anchored rocks.
- the force of the crepe shift due to pressure;
- stresses in the support elements.

The mass of anchored enclosing rocks creates certain stresses in the support elements, so that the proposed support meets all the requirements for its effective operation, the magnitude of the stress-strain state of its elements should be less than the strength of the support material.

The magnitude of the external forces acting on the support elements is not the same. Under the influence of these forces, the structure of the support elements is deformed. Excessive deformation will affect the quality and security of the support, so the amount of deformation set was compared with the amount of deformation obtained with the Autodesk Inventor program. Comparison is carried out in the space X, Y, Z and the values of safe deformation are determined.

Studies have shown that when the forces of the crepe elements do not have the same external forces, some of the rigidly bonded portions of the support face the crease shift phenomenon.

When the displacement arises excessively, the support goes into a dangerous state, so the amount of crease displacements should not exceed the safe value.

Under the action of surface layers, a pressure appears on the surface of the support. When this pressure is less than the standard tensile strength of the support material, the support meets the requirement for strength and stability.

Based on the simulation results, safe values of displacements and pressures are determined. The deformations of the proposed support from the action of

external forces, determined from the results of modeling, showed that for the conditions studied the magnitude of the deformation does not exceed the permissible values and the support is stable.

Thus, it can be concluded that the proposed combined flexible support is fully operational and can be effectively used.

CONCLUSION

In the thesis, an important national economic task was solved, representing scientifically sound technical and technological developments that ensure an improvement in the quality of fastening of mine workings by erecting a flexible support with a high degree of mechanization.

The performed researches allow making the following conclusions and recommendations.

1. To increase the effective work of the support of mine workings, it is expedient to use flexible supports that allow displacements and deformations beyond the limits of elastic stresses while maintaining their bearing capacity.

2. The construction of a compliant combined support with adjustable compliance is proposed, consisting of belts of tubular hydraulic-lifting anchors and a reinforced concrete arch erected in a certain order. During the intensive displacement of rocks, only tubular hydraulic anchors with a given load-bearing capacity work, and by the end of this period the reinforced concrete arch suspended to the anchors rests on the soil of the fixed workings and is included in the work.

3. Based on the views on the joint work of anchors with anchored enclosing rocks, an anchor-anchored rock model is proposed, based on an anchor scheme that is a closed contour of a complex outline loaded with a symmetrically uniformly distributed load.

4. A methodology has been developed for calculating and predicting the main characteristics of a hydraulically-supported tubular anchor support based on the revealed regularities of the dependence of the bearing capacity of the anchor on the pressure liquid expansion, providing a complete opening of the tubular anchor and the characteristics of the anchored rocks.

5. To improve the quality and improve the efficiency of the erection of a sprayed concrete support, it is advisable to use a new principle, a centrifugal supercharger, which allows the construction with full mechanization of supports up to a thickness of 200-250 mm per pass.

6. The technique of computer modeling of loads on the elements of a centrifugal supercharger is developed and the rational dimensions of the supercharger blades have been established based on the results of the research.

7. A technique for computer simulation of the work of combined flexible support has been developed and a qualitative characteristic of the loads on such support has been obtained.