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«ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ

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IMPROVING THE DESIGN OF A PNEUMATIC MIXER FOR THE PRODUCTION OF MULTI-COMPONENT MIXTURES

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Abstract. Introduction. The paper presents the process of improving the design features and technological capabilities of the basic device of a pneumatic mixer for the production of various multicomponent mixtures using numerical modeling of its operating modes in the SolidWorks Simulation software package. The application of the pneumatic mixer capabilities to create dry building mixtures used as injection solutions for filling technogenic voids in underground mining is considered. When analyzing the design modifications of the structure, the intensity of the vortex flow was taken into account due to additional tangential blowing to eliminate stagnant zones. The results of research in the field of improving the device in order to intensify technological processes inside the mixing chamber of the unit were the expansion of its technological capabilities, improved quality of mixed components under various conditions and materials, increased gross productivity for the finished product for all types of materials and relatively low energy costs for their homogenization. The mechanisms of mixture movement under the action of the air energy carrier and mixture particles of different sizes are explained.

Keywords: pneumatic mixer, mixing chamber, aerodynamics, two-phase flow, speed, particle, energy carrier, multicomponent mixtures, injection solutions, underground mining method.

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КӨП КОМПОНЕНТТІ ҚОСПАЛАРДЫ ӨНДІРУГЕ АРНАЛҒАН ПНЕВМАТИКАЛЫҚ АРАЛАСТЫРҒЫШТЫҢ КОНСТРУКЦИЯСЫН ЖЕТІЛДІРУ

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Аннотация. Кіріспе. Жұмыста SolidWorks Simulation бағдарламалар пакетінде оның жұмыс режимдерін сандық модельдеу арқылы әртүрлі көп компонентті қоспаларды өндіруге арналған пневматикалық араластырғыштың негізгі құрылғысының дизайн ерекшеліктері мен технологиялық мүмкіндіктерін жетілдіру процесі ұсынылған. Пайдалы қазбаларды өндірудің жерасты әдісімен техногендік қуыстарды толтыру үшін инъекциялық ерітінділер ретінде қолданылатын құрғақ құрылыс қоспаларын жасау үшін пневматикалық араластырғыштың мүмкіндіктерін қолдану қарастырылған. Құрылымдық модификацияларды талдау кезінде тоқырау аймақтарын жою үшін қосымша тангенциалды үрлеу арқылы құйынды ағынның қарқындылығы ескерілді. Агрегаттың араластырғыш камерасының ішіндегі технологиялық процестерді қарқындату мақсатында құрылғыны жетілдіру саласындағы зерттеулердің нәтижелері оның технологиялық мүмкіндіктерін кеңейту, әртүрлі жағдайлар мен материалдар кезінде араластырылатын компоненттердің сапасын арттыру, материалдардың барлық түрлері үшін дайын өнім бойынша жалпы өнімділікті арттыру және оларды гомогенизациялауға салыстырмалы түрде төмен энергия шығыны болды. Ауаның энергия тасымалдаушысы мен әртүрлі мөлшердегі қоспаның бөлшектерінің әсерінен қоспаның қозғалу механизмдері түсіндірілді.

Түйін сөздер: пневматикалық араластырғыш, араластырғыш камера, аэродинамика, екі фазалы ағын, жылдамдық, бөлшек, энергия тасымалдаушы, көп компонентті қоспалар, айдау ерітінділері, жерасты қазу әдісі.

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СОВЕРШЕНСТВОВАНИЕ КОНСТРУКЦИИ ПНЕВМОСМЕСИТЕЛЯ ДЛЯ ПРОИЗВОДСТВА МНОГОКОМПОНЕНТНЫХ СМЕСЕЙ

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Аннотация. *Введение.* В работе представлен процесс совершенствования конструктивных особенностей и технологических возможностей базового устройства пневмосмесителя для производства различных многокомпонентных смесей с помощью численного моделирования режимов его работы в пакете программ SolidWorks Simulation. Рассмотрено применение возможностей пневмосмесителя для создания сухих строительных смесей, используемых в качестве инъекционных растворов для заполнения техногенных пустот при подземном способе добычи полезных ископаемых. При анализе конструктивных модификаций конструкции учитывалась интенсивность вихревого потока за счет дополнительных тангенциальных поддувов для устранения застойных зон. Результатами исследований в области совершенствования устройства с целью интенсификации технологических процессов внутри смесительной камеры агрегата стали расширение его технологических возможностей, повышение качества перемешиваемых компонентов при различных условиях и материалах, увеличение валовой производительности по готовому продукту для всех типов материалов и сравнительно низкие энергозатраты на их гомогенизацию. Объяснены механизмы движения смеси под действием энергоносителя воздуха и частиц смеси различного размера.

Ключевые слова: пневмосмеситель, смесительная камера, аэродинамика, двухфазный поток, скорость, частица, энергоноситель, многокомпонентные смеси, инъекционные растворы, подземный способ разработки.

Introduction. The transition from open-pit mining of mineral deposits to underground mining implies the need to protect the earth's surface from destruction, which forces a multiple increase in the volume of construction materials used. The volume of consumption of concrete mixtures in the mining industry increases due to concrete for filling man-made voids, as well as dry construction mixtures (DCM) used as injection solutions (Golik, et.al., 2017; Prischepa, et.al., 2023; Lesovik, et.al., 2023). With an increase in the depth of mining operations, deformation of the rocks of the rock mass occurs, and the intensity of deformation of the enclosing rocks occurs significantly ahead of the growth of the development depth. Therefore, it is important to consider a number of materials for strengthening disturbed sections of massifs during underground mining operations. One of the possible methods for solving this problem is the use of injection solutions to strengthen and stabilize rocks, prevent collapses and landslides (Nasyrov, et.al., 2024; Golik, et.al., 2021; Berkovich, et.al., 2017). They can be used to fill cracks and voids, strengthen weak zones, increase the strength and stability of rock masses, which leads to a decrease in their stratification and a decrease in the risk of their destruction. Such solutions are obtained by mixing dry construction mixture with water. In addition to the component composition, the quality of SSS is determined by the technology of their preparation, in which the main role is played by the use of high-performance and energy-efficient mixing equipment. At enterprises of the building materials industry producing multi-component mixtures (SSS; dry paints; fire-retardant powder mixtures and materials, etc.), the use of rotor, blade, screw and pneumatic mixers is popular (Tumanov, et al., 2022; Gendler, et al., 2021). In the production of SSS for the creation of artificial massifs in underground conditions and the production of injection solutions in order to increase the efficiency of products in terms of mixing and homogenization of dispersed components, as well as reducing the energy intensity of technological processes, pneumatic mixers are becoming increasingly popular. In this regard, researchers are faced with the task of improving such units, ensuring an increase in their gross productivity for the finished product and a decrease in specific energy costs for production (Kharchenko, et.al., 2011).

It is known from work (Kuzin, et.al., 2015) that the most promising units for homogenization of dispersed components of mixtures are continuous pneumatic mixers, which, in comparison with the previously mentioned mixers, allow producing mixtures with a high coefficient of homogeneity of the mixture ($k = 0.8$–0.97), and the total energy consumption in this case can reach 10–16 kW h/t. To carry out homogenization of dispersed powder materials by pneumatic mixers, an energy carrier is required - compressed air. Pneumatic mixers designed in a special way allow producing multi-component mixtures in a continuous cycle, i.e. on the same flow of energy carrier, loading of components, their further mixing and unloading simultaneously occur. As alternative studies have shown in work (Uvarov, et.al., 2021), due to such a technological path in the volume of the mixing chamber of the unit, high quality of the finished product is achieved. In this case, the specific energy consumption for supplying compressed air, transporting components to the mixing chamber and homogenization inside the chamber with unloading per ton of conventional multi-component mixture depending on the components being mixed will be significantly lower than that of rotary, blade or vortex mixers.

However, in view of the use in industry of a wide range of dry multi-component mixture compositions, in order to increase the stability of rocks, it is necessary to differentiate pneumatic mixers by their efficiency for a particular technological task, to improve the process of mixing dry dispersed components in pneumatic mixers depending on the type and purpose of the mixture, taking into account the physical and mechanical characteristics of the materials being mixed, as well as the method of mixing the components (Martirosyan, et al., 2025; Kukharova, et al., 2024; Polekhina, et al., 2022). Therefore, improving the design of pneumatic mixers in order to expand their technological capabilities is a very urgent task.

A team of scientists has developed various designs of pneumatic mixers (Orekhova, et.al., 2018), which meet wide requirements in the production of various multi-component mixtures.

Materials and Methods. The objective of the study was to improve the design of continuous pneumatic mixers for the production of multi-component mixtures by numerical modeling in order to expand their technological capabilities, improve the quality of the mixed components, and increase the gross productivity of the finished product with the lowest values of specific energy consumption.

The object of the presented study is the original design of a pneumatic mixer, the experimental sample is shown in Figure 1, which was improved due to the need to perform various technological tasks in the field of production of dry multi-component mixtures.

Fig. 1. Experimental sample of the basic design of a pneumatic mixer

To intensify the homogenization process inside the basic structure of the mixing chamber of the unit (Figure 2), instead of non-adjustable blowing holes (pos. 5), adjustable end blowing pipes are provided, shown in Figures 3 and 4 (pos. 8), to eliminate stagnant zones with the selected original curvilinear geometry of the chamber itself for mixtures of different densities.

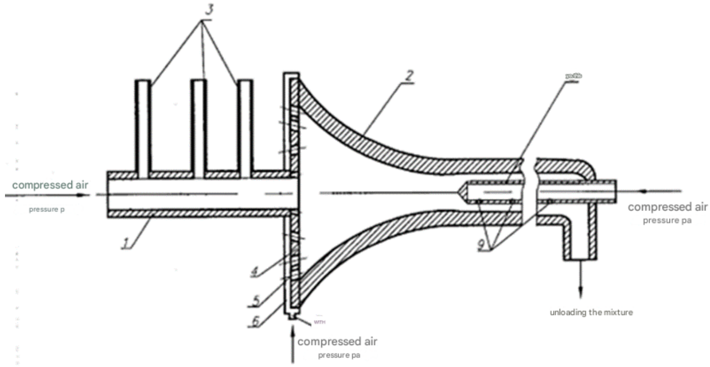


Fig. 2. Design of an experimental sample of the basic design of a pneumatic mixer, shown in Figure 1 (Orekhova, et.al., 2018): 1 – accelerating pipe; 2 – homogenization chamber; 3 – supply of mixture components; 4 – inclined aeration holes; 5 – blower holes to eliminate stagnation zones; 6 – air supply chamber; 7 – supply of blowing air; 8 – aerating device; 9 – holes of the aeration device

Fig. 3. Structurally and technologically improved mixing chamber in accordance with (Orekhova, et.al., 2018) (the mixing chamber is made with adjustable blower pipes)

In the process of homogenization, the aerodynamics of the mixing chamber, the geometric characteristics of the particles of dispersed components (their sphericity or windage), the speed modes of the unit, the required predicted quality of the finished product (uniformity coefficient), the productivity and energy consumption of the equipment have a special influence on the formation of the design and technological features of the pneumatic mixer.

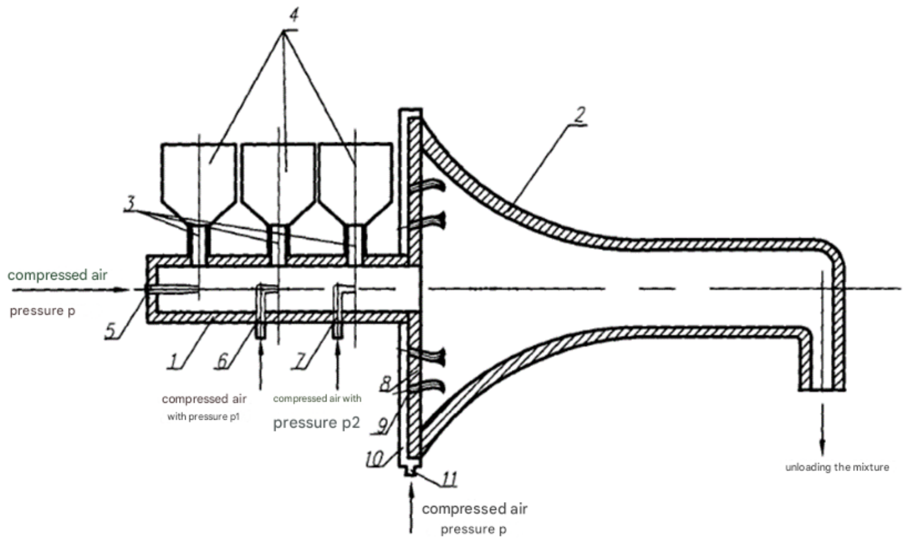


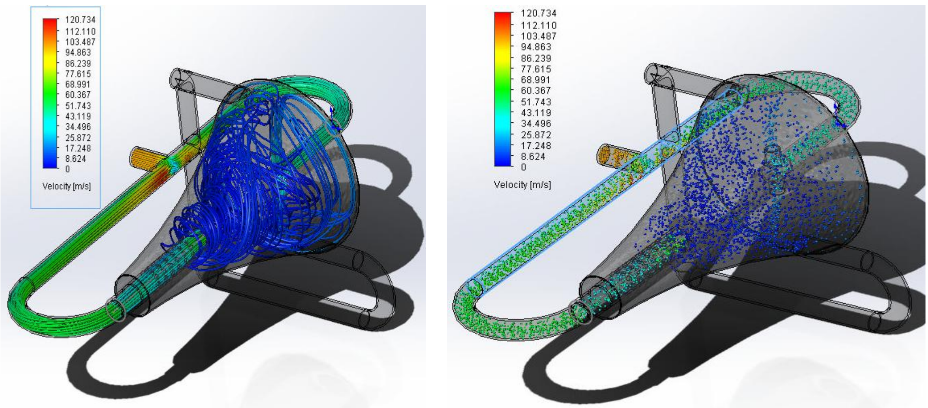
Fig. 4. Design of a continuous air mixer with adjustable blower pipes (Orekhova, et.al., 2018): 1 – accelerating pipe; 2 – homogenization chamber; 3 – dispensers of mixture components; 4 – bins for mixture components; inclined aeration holes; 5 – ejector; 6, 7 – additional ejectors; 8 – supply of blowing air through the nozzles; 9 – adjustable nozzles; 10 – energy carrier injection chamber; 11 – energy supply

The adjustment of the blowing nozzles should be carried out not only by the angle of the flow swirl, but also by moving them along the radius of the end of the homogenization chamber. This will increase the efficiency of the component mixing process, completely eliminate stagnant zones on the periphery of the homogenization chamber and increase the productivity of the pneumatic mixer for the finished product. However, such nozzles for heavy dry mixes and mixtures with reinforcing fillers have proven themselves unsatisfactory. Therefore, it is necessary to improve the design, unify its technological capabilities for mixtures with different bulk densities.

Research results.

In the pneumatic mixer designs (Orekhova, et.al., 2018) mentioned above, various dispersed components and systems can be homogenized: dispersed-reinforced mixtures, lightweight dry mixtures, activated cement with coloring pigments, etc. The feasibility of modeling modern equipment with the planning of underground mining makes it possible to check the design parameters, eliminate problems and shortcomings of the equipment and the selected technology as a whole (Antonov, et al., 2021; Kondratyev, et al., 2024). Figure 5 shows the results of the numerical calculation model of the absolute velocity of the carrier phase - air (Figure 5 a) and solid particles of the mixture with an average weighted particle size of 25 μm (Figure 5 b).

The trajectories of air and material flows inside the mixing chamber are shown in the range of speeds: respectively, for the energy carrier – air – from 9 m/s to 37.5 m/s, for solid particles – from 8.624 m/s to 34.496 m/s.



a) b)

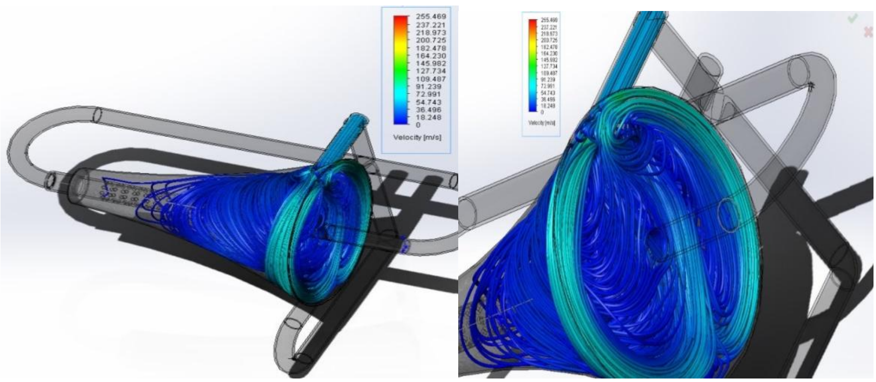
Fig. 5. Speed parameters of the carrier phase movement (a) and solid particles (b) in a pneumatic mixer for mixed components with ρav = 2200 kg/m3

This result satisfies the requirements of the Navier-Stokes differential equation system for three-dimensional particle motion, reflected in expression (1) for numerical modeling of two-phase flows (Orekhova, et.al., 2018):

$$\begin{cases} \dfrac{dv_0}{dt} = \dfrac{(v_0 - v_p)}{\tau} - \dfrac{1}{\rho_p} \bullet \dfrac{\partial p}{\partial r_e} + \dfrac{w_p^2}{r_e} \\ \dfrac{dw_0}{dt} = \dfrac{(w_0 - w_p)}{\tau} + \dfrac{v_p w_p}{r_e}, \\ \dfrac{du_0}{dt} = \dfrac{(u_0 - u_p)}{\tau} - \dfrac{1}{\rho_p} \bullet \dfrac{\partial p}{\partial h_0} + g. \end{cases}, \quad (1)$$

where v_p, w_p, u_p - are the radial, tangential and axial velocities of a particle in a vortex two-phase flow, m/s; v_0, w_0, u_0 are the radial, tangential and axial velocities of the energy carrier, m/s; t - is the average simulated relaxation time of the ground particle, s; τ - is the calculated relaxation time of the average-weighted particle in the energy carrier flow, s; p is the pressure created by the energy carrier, Pa; r_e - is the current radius of the mixing chamber of the unit, m; h_0 - is the relative axial coordinate of fixation of a solid particle in the air flow inside the mixing chamber of the unit, m; g is the acceleration of gravity, 9.81 m/s.

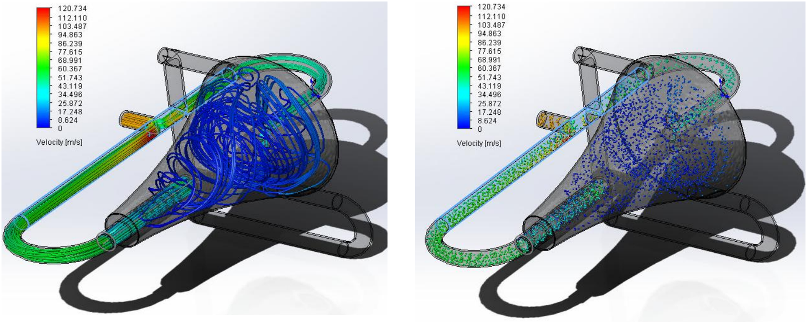
Discussion. However, it should be noted that the intensification of the mixed material flows is carried out in this design of the pneumatic mixer due to the additional tangential supply of the energy carrier through the pipes diametrically installed on the periphery of the mixing chamber, as shown in Figure 6. For example, for mixtures with high bulk density (for example, heavy cement-sand mixtures), tangential blowing of the energy carrier is simply necessary. It is the formation of an intensive vortex flow inside the mixing chamber that makes it possible to increase the productivity of the unit for the finished product, as well as improve the quality of the mixture (increase the homogeneity coefficient to 0.85–0.9). Additional tangential blowing also allows you to avoid possible stagnant zones in the mixer, which can negatively affect the quality of the mixture and the efficiency of the unit as a whole.



a) b)

Fig. 6. Speed parameters for intensifying mixing of heavy components among themselves by blowing the energy carrier (air) from tangential opposite directions of the peripheral part of the mixing chamber: a – general specifics of the dynamics of the air flow; b – enlarged image of the influence of two injection points on the intensity of mixing of heavy mixtures

An analysis of the speed parameters of air movement near the blower pipes shows that the average speed of the energy carrier in this zone is 61 m/s, which, in turn, is sufficient to intensify the mixing of components inside the mixing chamber, and on the other hand, does not lead to additional overgrinding of the components.



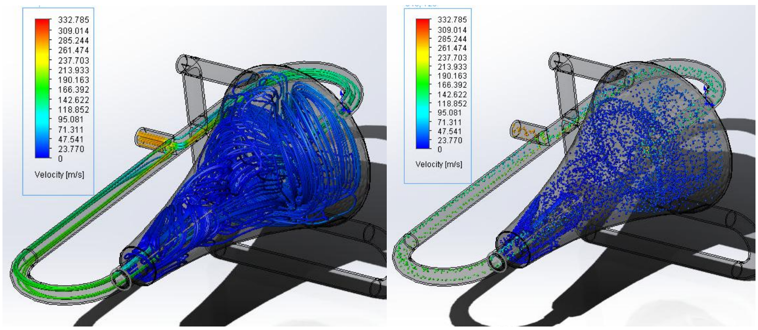
a) b)

Fig. 7. Speed parameters of the movement of the carrier phase (a) and solid particles (b) in a pneumatic mixer for light mixed components with ρ_{av} = 2200 kg/m^3

A similar picture of the aerodynamics of a two-phase flow is observed in the mixing chamber of a pneumatic mixer when mixing the components of a mixture with a bulk density of ρ_{cp} = 2500 kg/m^3. The results of numerical modeling are shown in Figure 7.

The speed modes of the unit's operation are 1.15 times higher than the operating modes on light mixtures with ρ_{cp} = 2200 kg/m^3. This is due to the special role of gravity and the relaxation time of particles in the air flow. Analysis of the system of equations (1) confirms this conclusion.

Figure 8 shows the results of numerical modeling of the technological process of homogenization of a dispersed-reinforced mixture with a bulk density of ρ_{cp} = 2720 kg/m^3.



a) b)

Fig. 8. Speed parameters for intensifying mixing of heavy components with reinforcing fibers (metal fiber) by blowing energy carrier (air) from tangential opposite directions of the peripheral part mixing chamber: a – general specifics of air flow dynamics; b – trajectories of heavy particles depending on the speed of the energy carrier – air

For efficient mixing of heavy dispersion-reinforced mixtures using, for example, basalt fiber, speed modes are required that are 2.8 times more intense than for light mixtures. Here, the speeds inside the mixing chamber reach maximum values - 71 - 82 m / s, and on the acceleration track - up to 180 m / s. Various physical and mechanical characteristics of SSS require the use of different speed modes for mixing the components. Consequently, the speed indicators with an increase in the bulk density of the mixture, different particle diameters, and volume concentration in the energy carrier flow - grow. This means that in order to achieve a combination of these indicators, it is necessary to ensure rational and sufficient operating modes of the pneumatic mixer for efficient operation.

Conclusion. As a result of numerical modeling of the process of homogenization of dispersed mixtures in the volume of the mixing chamber, rational modes of operation of the pneumatic mixer were identified, and design and technological changes in the mixing chamber were proposed in order to improve and unify the pneumatic mixer.

As a result of numerical modeling, it was found that depending on the physical and mechanical characteristics of the mixed components (average bulk density and average weighted particle size), the rational mode of operation of the unit changes: for light mixtures, the range of absolute velocity of the energy carrier is from 9 m / s to 37.5 m / s, for solid particles - from 8.624 m / s to 34.496 m / s; for mixtures with ρ_{cp} = 2500 kg / m^3, respectively, 1.15 times more than for light mixtures; for heavy dispersed-reinforced mixtures - 2.8 times more than for light mixtures. Thus, the use of an improved pneumatic mixer ensures a reduction in the energy intensity of the technological process and an increase in the efficiency of mixing and homogenization of dispersed components in the technology of producing dry building mixtures for obtaining injection solutions. In turn, improving the quality of injection building mixtures will ensure an increase in the stability of rock massifs.

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