UDC 622.831 DOI: https://doi.org/10.1051/e3sconf/201910900090

ORGANIZATION OF GEOMECHANICAL MONITORING FOR NON-METALLIC DEPOSITS CHAMBERS ROOFS

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ОРГАНІЗАЦІЯ ГЕОМЕХАНІЧНОГО МОНІТОРИНГУ ПОКРІВЛІ КАМЕР НЕРУДНИХ РОДОВИЩ

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ОРГАНИЗАЦИЯ ГЕОМЕХАНИЧЕСКОГО МОНИТОРИНГА КРОВЛИ КАМЕР НЕРУДНЫХ МЕСТОРОЖДЕНИЙ

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Annotation. The work is aimed at improving mechanisms for controlling the stress-strain state of large underground mine workings with a chamber-pillar system of mining. The aim of the work is the development and implementation of methods and special equipment for monitoring and diagnosing the state of the roof of mine workings of non-metallic mineral deposits, which ensure long-term operation of large section chambers. Using the example of the gypsum mine of the Siniat ALC in Bakhmut, Ukraine, the stages of development of deformation processes in the roof of highly loaded workings are shown. The accelerated development of deformations in zones of geological disturbances is established. The necessity of organizing integrated control of the roof of mine workings as the weakest link in the underground geomechanical system is substantiated. The task of improving the safety of mining at the mine was accomplished by organizing and conducting geomechanical monitoring of the state of the roof of mine workings. Monitoring involves the provision of operational monitoring of the situation in a particular area of the mine field. This makes it possible to implement organizational and technical solutions that exclude the occurrence of an emergency and reduce the damage from exposure to incorrigible natural factors. To solve diagnostic problems of varying complexity, three levels of monitoring are recommended. The effectiveness of the integrated use of visual observations, instrumental measurements and vibro-acoustic diagnostics of the state of the roof is established. Examples of long-term monitoring of dangerous sections of roofing workings are given. Improving the monitoring of the condition of the roof of underground mine workings with a chamber-and-pillar system for the development of non-metallic mineral deposits allows increasing the level of safety in the mine and preserving the environment. The development does not contradict the requirements of national regulatory documents in the field of labor protection. Monitoring is technically and economically adapted to the capabilities of the production structure of the enterprise. Monitoring experience can also be recommended for mines producing anhydrite, limestone and marble.
Keywords: monitoring, diagnostics, big section chambers, deformation of the roof, gypsum mine.

Introduction. Considerable part of nonmetallic construction raw materials in the world are mined underground. Mostly use chamber-and-pillar system of development. Parameters of chambers of some deposits are specified in Table 1.

By the sizes, chambers belong to developments of big section. It imposes increased requirements to control of a condition of a roof of workings, especially taking into account the insignificant depth of fields and existence on a surface of objects of civil, industrial and agrarian function. The market value of the extracted mineral raw materials is small. Service life of chambers is decades. Fastening of a roof of chambers is incidental. Natural geomechanical processes in rock mass promote gradual decrease in stability of a roof of chambers. In the absence of control, the caving of a roof is possible. Large accidents in gypsum mines in Nikitovka (Ukraine), Shante-Lu (France) and Koshava (Bulgaria) are known. In zones of geological faults mining operations provoked inrushes in a roof and on the gypsum field in Bakhmut (Ukraine). As a result of it on the land surface pits were formed (Figure 1).

Table 1 – Chambers parameters of some building materials deposits

Country	Raw materials	Deposit	Depth, m	Height, m	Width, m
Ukraine	gypsum	Artemivske	70 - 100	15 - 18	8 - 11
	limestone	Novo-Odesske	20 - 30	5.2	6 - 8
		Inkermanske	20 - 30	13	8 - 12
Russia	gypsum	Novomoskovskoye	110 - 130	9 - 11	10 - 11
	anhydride	Gorosubovskoye	130 - 150	9 - 14	8
	marble	Kibik-Kordonskoye	150 - 200	12 - 18	8 - 12
Moldova	limestone	Grigoriopol	40 - 70	5.2	5 - 9
		Chisineu	70 - 100	2.6	8
Italy	marble	Carrara	20 - 30	8 - 10	4 - 6
		Candoglia	30 - 50	18 - 22	8 - 10
Portugal	marble	Alentejo	65 - 90	10 - 14	9

Figure 1 – The pit over gypsum mine workings in Bakhmut (Ukraine)

Emergence of contingency situations in mines is promoted by the following factors: the long life of workings, increase in total length of constantly used workings, complication of mining and geological conditions. Necessary condition of safety of work of mines and surrounding medium is the organization of geomechanical monitoring of a condition of a roof of workings. Further the developed structure of monitoring for the gypsum mine of ALC "Siniat" (Bakhmut, Ukraine) of the international concern "Etex Group" is given. At the enterprise, the

European requirements to the culture of production and safety of work of miners successfully are implemented.

The long joint creative commonwealth of specialists of the ALC "Siniat" and scientists of Institute of geotechnical mechanics of National Academy of Sciences of Ukraine allows in difficult mining and geological conditions to conduct profitable operation of the deposit. Creation of a complex system of observations of a condition of workings became one of successfully implemented projects of cooperation. Its major element is control of a roof. It is carried out in common by specialists of the enterprise and institute. When organizing the control, the results of monitoring at gypsum deposits of Russia (Kamsko-Ustinskoye, Peshelanskoye and Novomoskovskoye) [1] were taken into account. The best methodological and instrumental developments of other organizations are taken into account [2-7].

Preferable use of one of methods was the first flaw of the schemes of control used earlier. The prevailing place was taken by visual inspection. Other methods were used fragmentary and did not make a whole system.

The second flaw consisted in definition of a condition of a roof only by results of the current diagnostics. The executed researches showed that dynamics of development of deformation processes in a roof is crucial. At some point, the quantitative accumulation of defects in rock mass passes into qualitative. Sign of a dangerous state is not the absolute value of parameter, but its jump. Therefore the following requirements were imposed to monitoring: to provide operational control of the situation on the concrete site of the mine field; to provide a possibility of realization of organizational and technical solutions which exclude emergency or reduce damage from influence of ineradicable natural factors; not to contradict requirements of national normative documents in the sphere of labor protection; to be technically and economically coordinated with opportunities of production structure of the enterprise.

Methods. The developed technique takes into consideration the main mining, geological and technological situations at operation of developments and has flexible structure. Taking into account the extensive nomenclature and continuous modernization of technical means their concrete types were not discussed.

By the complexity level three levels of geomechanical monitoring are provided: low, carried out on the sites by the master, the mine master, the head of the site according to requirements of safety rules [8]; medium, carried out by service of overseeing by excavations, including documenting of results of observation and roughing-out of data array; high, carried out by one or several specialized organizations with a necessary hardware on separate, particularly complex, sites of the mine field.

Time frames of realization of monitoring provide operating, current, long-term and specialized types of monitoring of a condition of a roof of underground chambers. Features of their realization for different levels of monitoring in Table 2 are displayed. For different levels of monitoring a particular set of the used control methods is provided (Table 3).

Table 2 - Application conditions of different monitoring forms

Type of monitoring	Monitoring level		
	low	medium	high
Operating	in shifts	if necessary	-
Current	everyday	on the approved schedule	-
Long-term	-	on the approved schedule	continuously
Specialized	-	-	disposable

Table 3 – Roof control methods for different levels of monitoring

Monitoring level	Testing methods	
	basic	additional
Low	Visual inspection from floor of chambers	-
Medium	Survey with use of elevators, determination of geometrical parameters of the revealed defects, installation of beacons on cracks and monitoring of their state, registration of the stationary tools state, rock bolts condition survey	Drilling of control holes for determination of thickness of layers
High	Creation of electronic archive of photos of the most problem sites, vibroacoustic diagnostics, installation of means of constant control and their technical inspection	Selection and test of a core in vitro

According to requirements "Safety rules …" [8] monitoring of the lowest level is carried out in shifts by the head of change before works and daily the supervising foreman. Visual inspection without use of lifting tools allows revealing only the most significant changes of a geomechanical situation. Filing of results of inspection at this level has descriptive character. Monitoring of the average level provides detailed visual inspection of a roof with use of the telescopic elevator. At the same time fix the revealed defects and their geometrical parameters measure (Table 4).

Table 4 – Visually recorded defects of a roof

Type of defect	Characteristics (signs)	
	quantitative	qualitative
Crack	length, disclosure, shift of boards	"Healing" or development
The rock slab separating from the massif	geometrical dimensions	Stability in case of induce cavind
Replacement of a protective gypsum pack with soft rocks	area	Geological description of the replacing rocks
Site of moistening	area	Characteristic of extent of moistening
Damage of the "anchor with a grid" system	area of maintaining	Specification of defect: destruction, corrosion, etc.

Within monitoring of the medium level establish beacons for control of dynamics of disclosure of cracks. For short-term observations use plaster, cement and glass beacons. Their task consists in identification of the fact of increase in disclosure of a crack. For the long overseeing by dynamics of disclosure use bladed beacons. Their design and the scheme of installation are presented in Figure 2.

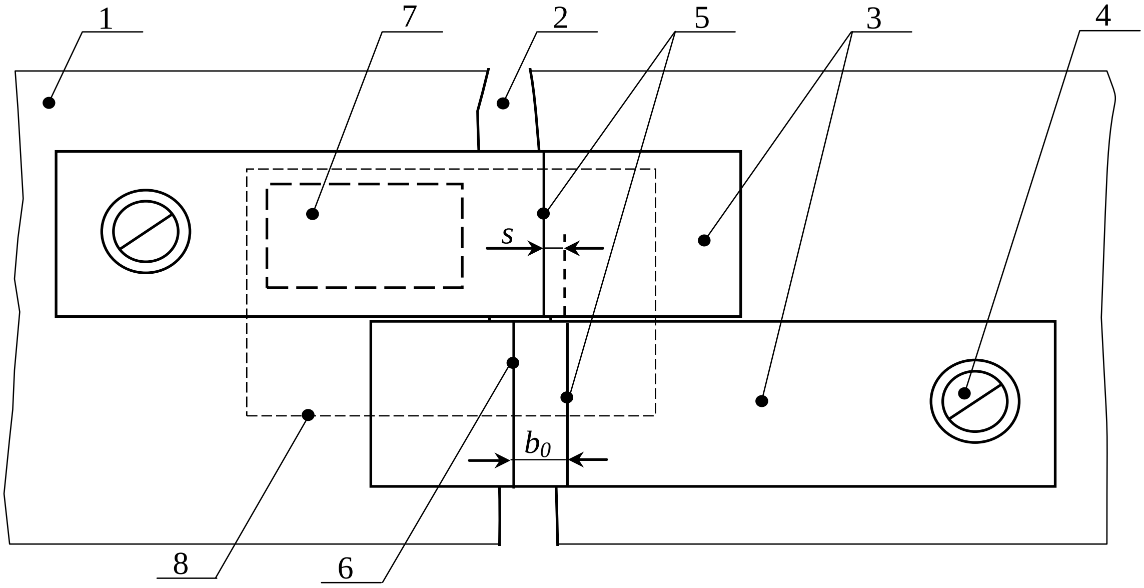

Figure 2 – Construction of the bladed beacon: 1 – roof, 2 – fracture, 4 – plate, 4 – rock bolt, 5 – sighting line, 6 – basic line, 7 – place for designation of beacon number, 8 – frame boundary when shooting

The sighting line 5 is drawn immediately after installation of the beacon in the form of a piece of the straight line passing through both plates. Basic line 6 is put on one of plates at in advance defined distance b_0. Process of monitoring consists in periodic photography of the beacon with high-res (not lower than 12 Megapixel). Segments of the hairline line on both plates, a part of the basic line and number of the beacon shall get into the shot. Also the installation mode is provided in a shot of date of photography. In case of computer processing of a picture with big increase define s/b_0 relation. Then on the known value of b_0 calculate real value of extension of s of a fracture from the moment of installation of the beacon. Resolution capability of monitoring in case of qualitatively the executed photos of the beacon makes order 0.2–0.3 mm. Accumulating electronic archive of photos, it is possible to keep track of dynamics of development of a fracture for a long time.

For execution of preventive engineering actions for support of maintenance of a roof in secure state it is necessary to know its building.

One of tasks of monitoring of the medium level is execution of control drilling. Determine thickness of layers in a roof by its results and its geological structure.

In case of high level monitoring execution the most problem sections are exposed to visual survey are photographed. The periodicity of photography accepted by default – once a quarter. In case of explicit progressing of deformation processes the temporal period between executions of monitoring is reduced. Place a measured tape for determination of the extent of defect in a frame. The example of the exfoliating rock slab in a roof of workings given in the Figure 3.

In case of computer processing of the picture the necessary linear extent of defect is determined. The analysis of electronic archive of photos for long time allows keeping track of dynamics of development of deformation processes in a ceiling of roof.

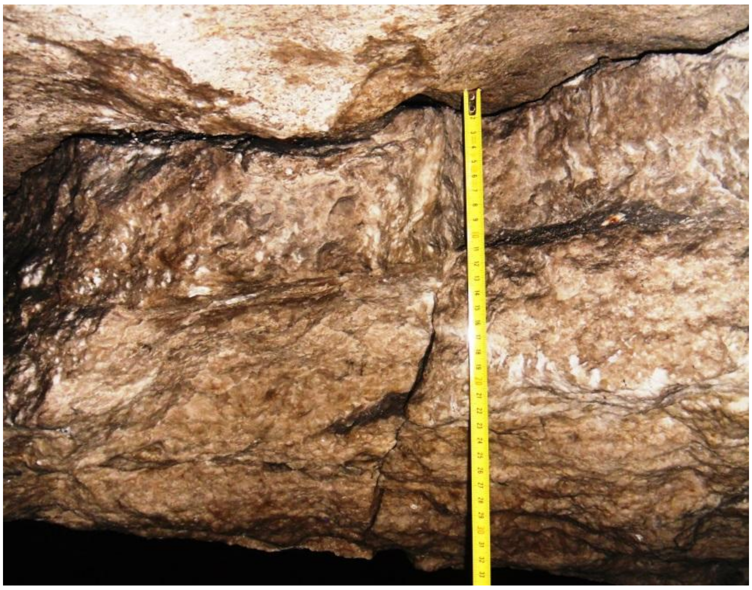

Figure 3 – A photo of separation in a roof of the main transport gallery

Vibroacoustic diagnostics allows revealing the latent defects on a section of rock mass in parameters of damped oscillations [9]. Excitation of oscillations is realized single shock. Diagnostics of a roof includes: primary continuous monitoring of a roof for identification of an incipient state of process of stratification in a protective pack which is not revealed in the visual path; repeated periodic monitoring of earlier revealed sites of stratification; assessment of stability of the revealed visually unstable blocks; assessment of stability of the pedigree blocks delineated by cracks on a roof surface.

The equipment description and operation instructions are provided in [10, 11]. Diagnostics of a roof is carried out from the telescopic elevator. The operator installs the contact receiver of vibration on a roof and about 1 m strikes blow in a controlled point apart. The equipment keeps result of monitoring on the given time slice. Process of monitoring is illustrated by Figure 4.

Figure 4 – Realization of vibroacoustic diagnostics of a roof of development by basic option

Because of the uncomfortable working position it is difficult for operator to strike at the same time the most powerful blow and to provide stable contact of the receiver with the massif. Therefore in basic option of monitoring the best results on informational content are yielded by parameter – a relaxation time of oscillatory process which does not depend at impact force. Despite limited base of monitoring and influence of a ghost mechanical pulse on the receiver through a cabin design after striking this scheme is used as the main. The scheme of vibroacoustic monitoring with big base is developed and approved. In this case the receiver has permanently in the place, comfortable for the recording equipment, and carry out exaltation of a roof step by step from a cabin of the telescopic elevator. When using such scheme oscillatory process of the site of a roof as the thick plate jammed on a contour it is almost localized in the neighborhood of a impact point. Other site of rock mass between the activator and the receiver serves as an acoustic wave guide. The scheme is illustrated by Figure 5.

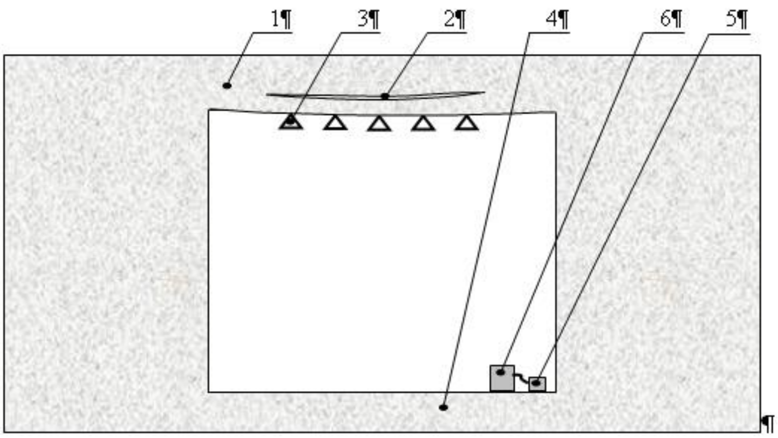

Figure 5 – The scheme of vibroacoustic diagnostics of a roof on big base of monitoring:
1 – ceiling of chambers, 2 – stratification, 3 – shock point, 4 – floor of chambers,
5 – vibration receiver, 6 – recording equipment

The scheme at realization of conditions is implemented: high and stable impact energy; high sensitivity of vibration receiver and its stable contact with a roof; low level of acoustic noise; the base of monitoring is much more sizes of the surveyed site.

High sensitivity of receiver and stable acoustic contact are provided with its fastening to the massif quick-hardening mix. Feature of distribution of a wave packet to the vibration receiver – natural frequency filtration of a signal. The low-frequency portion of a spectrum containing the resonances, characteristic of defects, fades less in comparison with high-frequency. On low frequencies when excitation defects the substantial increase of a vibration amplitude is registered. At stabilization of impact parameters change of level of a signal can exceed much the variations caused by instability of conditions of excitation of oscillations and also change of base of monitoring. From one installation of the receiver control up to 30 points.

For monitoring of a roof of the long workings with small roadway cross-section is used the scheme provided on Figure 6.

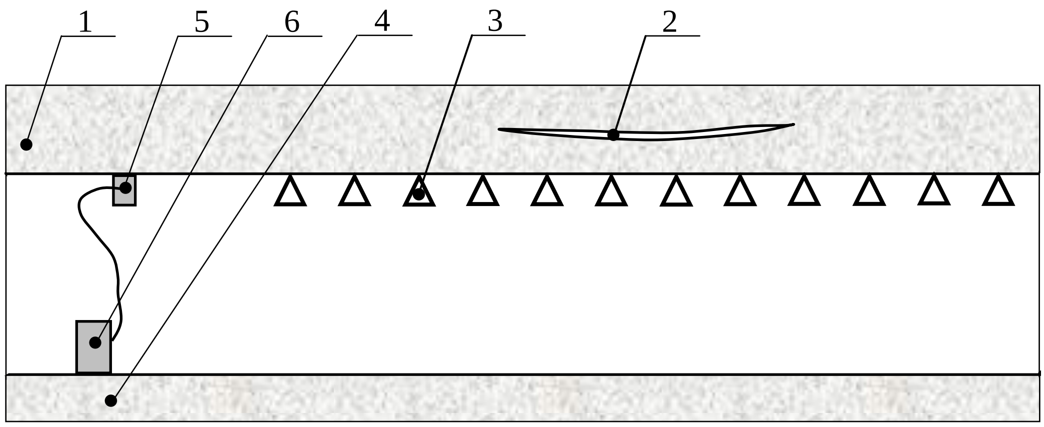

Figure 6 – The scheme of vibroacoustic diagnostics of a roof in development working:
1 – ceiling of chambers, 2 – stratification, 3 – shock point, 4 – floor of chambers,
5 – vibration receiver, 6 – recording equipment

When using such scheme for identification of the abnormal sites beforehand the established criteria values are not necessary. Their selection along a profile happens by comparison of values in more remote points in comparison with more close ones. In the absence of defects in a roof the initial vibration amplitude in a low-frequency portion of a spectrum monotonically decreases in process of removal of the receiver from an exaltation point. Sign of stratification is significant increase in amplitude, despite the increasing base of monitoring. The specified regularity is illustrated by Figure 7.

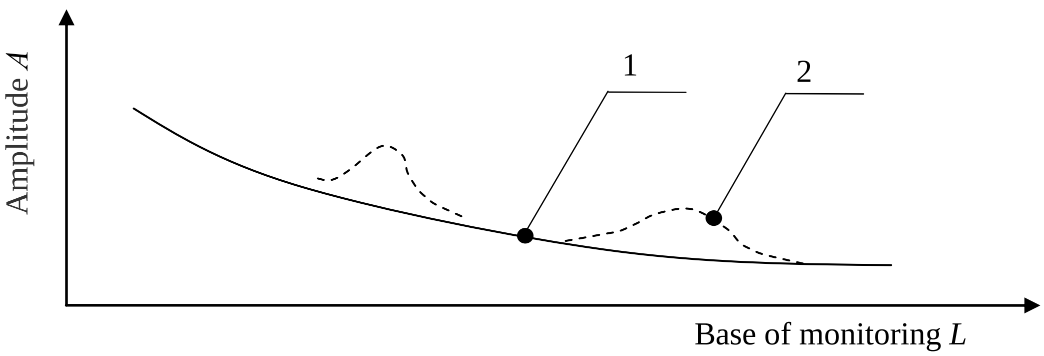

Figure 7 – Dependence of a vibration amplitude on base of monitoring for a roof of development working with existence and lack of stratifications: 1 – lack of stratifications in a roof, 2 – sign of stratification

Deformations of an immediate roof of the gypsum mine are very insignificant. The critical deflection of a protective pack is estimated of 10-20 mm. The modern laser registrars of deformations with a high precision provide measurements in the specified range [12]. However their use demands of additional attracting of the specialized organization. Optimal solution – use of the indicator stations set on deep bench mark. The station provides the measurement range of vertical deformation to 10 mm with resolution capability of 0.01 mm. With annual execution the service life of the station makes up to 10 years. On sections of the explicit movement of blocks the most reliable and convenient in operation were developed multistage signaling devices with the dropping-out signal elements.

The quantity of steps of operation is from 3 to 6 depending on design version. Every of steps is configured individually on operation at a certain deformation in the range about 1 up to 20 mm. Resolution capability of a threshold of operation makes 0.5 mm. Service life of signaling devices without test – not less than 10 years. The appearance of the signaling device of vertical deformations of a roof intended for installation on a deep bench mark is presented in Figure 8.

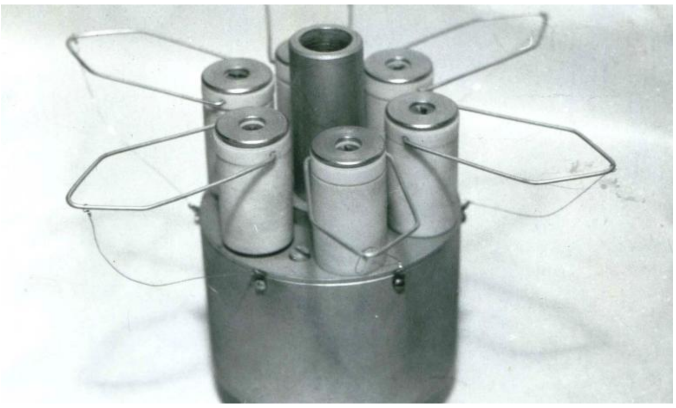

Figure 8 – Appearance of a six-step signaling device of roof deformations

In zones of carsts the significant change of properties of rocks is observed. For adjustment of the dimensions of chambers and pillars also the complex of characteristics of rocks is necessary for calculation of chart of supports. For this purpose the third level of monitoring provides sample drawing and their laboratories tests in institute. Definition to 12 characteristics is possible.

Results and discussion. The total duration of overseeing the gypsum mine workings with participation of institute is over 40 years. During the specified time there were irreversible geomechanical processes in the mine roof. They considerably reduced stability. The adjusted system of observations and timely performance of engineering preventive actions allowed to prevent the emergency development of situations and to save mine. The typical phenomenon in a roof of working, is gradual formation of block structure with threat of the subsequent caving. Long overseeing of indicator stations by network allowed revealing the main regularities of deformations in a roof of working (Table 5).

Table 5 – Deformations development dynamic in a gypsum mine working roof

Stage	Process	Duration, years	Speed of deformation, mm/year
1	Stratification of rocks of a roof	to 10	to 0.3
2	Formation of a single large fracture	2 - 5	0.3 – 0.5
3	Formation of large-block structure	1 - 3	0.5 -1.0
4	Formation of shallow blocks	to 1	more than 1

Dynamics of development of fractures and zone of stratification in a roof by results of vibroacoustic monitoring is illustrated on the example of chamber No. 31 of the VII stall (Figure 9).

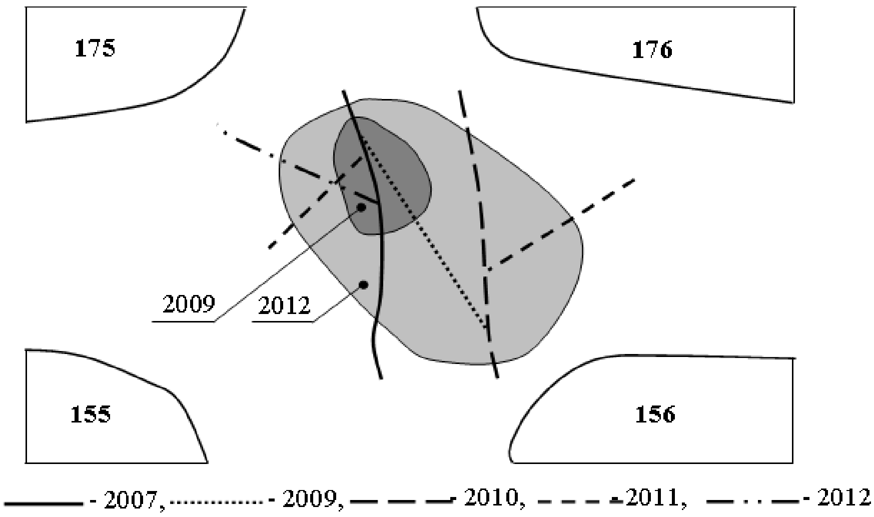

Figure 9 – Development by years of a system of fractures and increase of area of stratification in a ceiling of chamber

The chamber was fulfilled in 1992 and within more than 10 years its visual inspection did not show signs of violation of a roof. The first longitudinal fracture in a roof appeared in 2007, following – in 2009. The first signs of stratification in a roof received with use of a vibroacoustic method were also found in 2009. Development of block structure in a roof of working happened 4 years. Periodic measurements of disclosure of an initial longitudinal fracture were shown by its increase for the specified period from 5 to 10 mm. Disclosure of other fractures by 2012 made from 1 to 3 mm.

Regularly carried out vibroacoustic diagnostics showed the considerable expansion of a zone of stratification in a roof. Due to potential danger of further operation, working was closed access for people and machines. In two years there was a working roof caving.

In some cases deformation processes in a protective pack of a roof of workings don't fade and don't lead to emergence of new fractures. An example is the site of transport gallery between pillar No. 147, 148, 153 and 154. Working crossed by the single fracture, recorded at the end of the last century. On the basis of data of vibroacoustic diagnostics on the site the three-stage signaling device with a step of operation of steps of 2 mm was established.

Systematic overseeing by a condition of a signaling device showed the progressing lowering of the muck block in a roof from the pillars No 147 - 154. The first stage of a signaling device worked in 2012, and the second in 2018. Considerably the area of stratification of a protective pack increased in a chamber of roof. The condition of a roof on this site of the main transport gallery of the gypsum mine in December, 2018 is illustrated by Figure 10.

On sites of the mine take with geological faults of rock mass deformation processes happen more intensively. Local faults are grouped in zones. By results of monitoring 22 dangerous zones are allocated. Conducting mining operations on some sites is carried out on the special project. Some characteristics of three large dangerous zones are presented in Table 6.

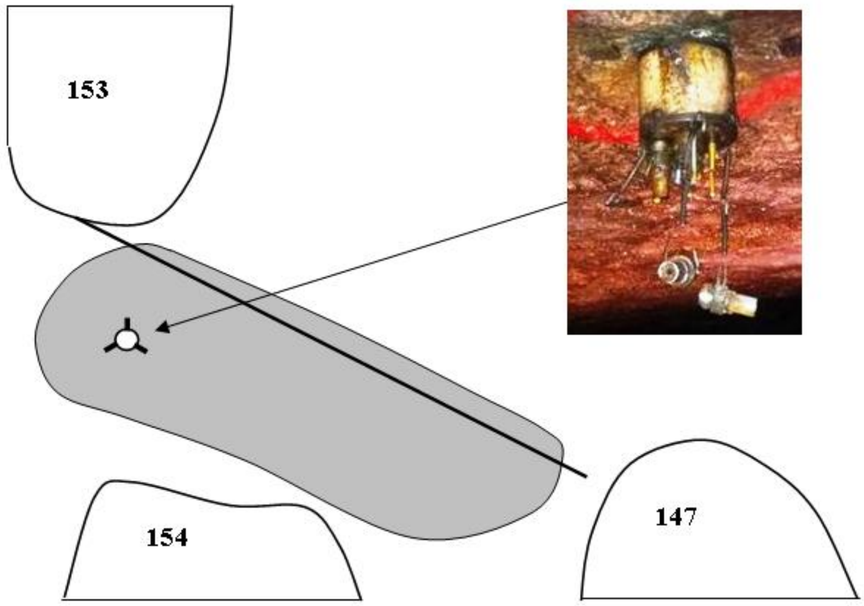

Figure 10 – The site of a roof vertical displacement on the main transport gallery between pillars No 153, 154, 147 with a view of the triggered deformations signaling device

Table 6 – Selection of dangerous zones by results of geomechanical monitoring

Conditional number	Area, m^2	Disposition of a zone (stall)	Typical forms of a faults of the massif
6	52100	IV, V, VI	Karst, partially humid
21	15200	VII	Karst, small-amplitude tectonics
22	17800	VII	Karst, with inrush of rocks in the chamber

Conclusions. Need of the organization of complex monitoring of the weakest link of an underground geomechanical system – a roof of workings is proved. Three levels of monitoring for diagnostics problem solving of varying complexity are recommended. The efficiency of complex use of visual observations, tool measurements and vibroacoustic diagnostics is established. On the example of the gypsum mine in Bakhmut stages of development of deformation processes in a roof of heave-gage workings are shown. Acceleration of their development in zones of geological flaws is established. Experience of the organization of monitoring can be recommended also for mines on extraction of anhydrite, a saw stone and marble.

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Анотація. Робота спрямована на удосконалення механізмів контролю напружено-деформованого стану підземних гірничих виробок великого перерізу для камерно-стовпової системи розробки корисних копалин. Метою роботи є розробка та впровадження методики, способів і спеціального обладнання для контролю і діагностики стану покрівлі гірничих виробок родовищ неметалевих корисних копалин, які забезпечують тривалу експлуатацію камер великого перерізу. На прикладі гіпсової шахти ТДВ «Сініат» в місті Бахмут, Україна, показані етапи розвитку деформаційних процесів в приконтурному масиві високонавантажених виробок. Встановлено прискорення розвитку деформацій в зонах геологічних порушень. Була доведена необхідність організації комплексного контролю слабкої ланки підземної геомеханічної системи, якою є покрівля виробок. Завдання підвищення безпеки гірничих робіт в шахті було вирішено організацією і проведенням геомеханічного моніторингу стану покрівлі гірничих виробок. Моніторинг передбачає забезпечення оперативного контролю ситуації на конкретній ділянці шахтного поля. Він також забезпечує можливість реалізації організаційних і технічних рішень, які виключають виникнення аварійної ситуації або зменшують збиток від впливу непереборних природних факторів. Рекомендується три рівня моніторингу для вирішення проблем діагностики різної складності. Встановлена ефективність комплексного використання візуальних спостережень, інструментальних вимірювань і віброакустичної діагностики стану покрівлі. Наведено приклади тривалого спостереження за небезпечними ділянками покрівлі виробок. Удосконалення системи контролю стану покрівлі підземних гірничих виробок при камерно-стовпової системі розробки корисних копалин нерудних родовищ дозволяє підвищити рівень безпеки роботи в шахті при одночасному збереженні довкілля. Розробка не суперечить вимогам національних нормативних документів у сфері охорони праці. Вона технічно і економічно адаптована до можливостей виробничої структури підприємства. Досвід організації моніторингу може бути рекомендований також для шахт з видобутку ангідриту, пильного вапняку, каменю і мармуру.

Ключові слова: моніторинг, діагностика, камери великого перерізу, деформації покрівлі, гіпсова шахта.

Аннотация. Работа направлена на совершенствование механизмов контроля напряженно-деформированного состояния подземных горных выработок большого сечения для камерно-столбовой системы разработки полезных ископаемых. Целью работы является разработка и внедрение методики, способов и специального оборудования для контроля и диагностики состояния кровли горных выработок месторождений неметаллических полезных ископаемых, которые обеспечивают длительную эксплуатацию камер большого сечения. На примере гипсовой шахты ОАО «Синиат» в городе Бахмут, Украина, показаны этапы развития деформационных процессов в приконтурной массиве высоконагруженных выработок. Установлено ускорения развития деформаций в зонах геологических нарушений. Была доказана необходимость организации комплексного контроля слабого звена подземной геомеханической системы, которой является кровля выработок. Задача повышения безопасности горных работ в шахте было решено за счет организации и проведения геомеханического мониторинга состояния кровли горных выработок. Мониторинг предусматривает обеспечение оперативного контроля ситуации на конкретном участке шахтного поля. Он также обеспечивает возможность реализации организационных и технических решений, исключающих возникновение аварийной ситуации или уменьшают ущерб от воздействия непреодолимых природных факторов. Рекомендуется три уровня мониторинга для решения проблем диагностики различной сложности. Установлена эффективность комплексного использования визуальных наблюдений, инструментальных измерений и виброакустической диагностики состояния кровли. Приведены примеры длительного наблюдения за опасными участками кровли выработок. Совершенствование системы контроля состояния кровли подземных горных выработок при камерно-столбовой системе разработки полезных ископаемых нерудных месторождений позволяет повысить уровень безопасности работы в шахте при одновременном сохранении окружающей среды. Разработка не противоречит требованиям национальных нормативных документов в области охраны труда. Она технически и экономически адаптирована к возможностям производственной структуры предприятия. Опыт организации мониторинга может быть рекомендован также для шахт по добыче ангидрита, пыльного известняка, камня и мрамора.

Ключевые слова: мониторинг, диагностика, камеры большого сечения, деформации кровли, гипсовая шахта.

Стаття надійшла до редакці 28.06. 2019
Рекомендовано до друку чл.-кор. НАН України О.П. Круковським