The Calculation Parameters for the Effective Seismic Sensors Placements to Monitor Burst-Hazard Rock Massif

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Abstract

An algorithm for constructing the optimal configuration of an observational network of a seismo-acoustic system for monitoring rock pressure has been developed. Software module was implemented based on the developed algorithm. It allows the construction of maps of the observation network sensitivity at current time and after the addition of seismic receivers. Two operating modes of the software module are implemented: in the first, a map is constructed based on gradient levels, in the second, based on control levels reflecting location confidence of seismic acoustic signals. Recommendations for working with the software module are given. Main shortcomings of the developed algorithm for constructing the optimal configuration of the observational network are indicated and directions for further improvement of the algorithm are formulated.

1 Introduction

As long-term practice shows, underground mining at a number of mining enterprises is complicated by shock-hazardous conditions. An increase in the number and intensity of various geodynamic phenomena is predicted with a further decrease in the horizons of mining [1, 2]. In these conditions, more in-depth research is needed. It includes the study of geodynamic fields laws and technogenic influence processes of mining operations using seismic, seismo acoustic, geodesic, seismic-deformation and other methods [3, 4].

Monitoring of the geomechanical state of a shock-hazardous rock mass using automated systems is one of the promising methods for preventing the occurrence of mountain and mountain tectonic impacts. These systems provide real-time registration and operational processing of the parameters of seismo acoustic events that contain information about geomechanical and geodynamic processes occurring in a massif [5-7].

The seismo acoustic monitoring system of rock pressure “Prognoz ADS” [8, 9] is a measuring and computing complex. An innovative approach was taken in developing this system. It provides the conversion of analog information into digital in the immediate neighborhood of the primary transducer (geophone). Further processing of monitoring data takes place in digital form.

This approach has the following advantages:

- wide dynamic range of transmitted signals;
- high noise immunity;
- the ability to remotely control, configure and remotely update the digital receiver firmware.

The system is divided into surface and underground parts. The underground part is represented by a distributed network of digital receivers-converters with connected primary converters and an underground equipment room in which repeaters and power supply are located. They also perform functions of a time synchronization signal generator.

The surface part is a center for receiving and processing seismic pulses. It is organized on the basis of a personal computer with installed specialized software. The connection between the underground and surface parts is realized through the main communication line.

The task of optimal configuration of a distributed observational network.

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A key element of the developed system is a distributed observational network of underground digital receiving transducers. Each of them is made in the borehole version and consists of a piezoceramic-type primary transducer (geophone) and an acoustic signal preprocessing unit (digital receiver of the transducer).

Digital receivers and primary transducers are installed in horizontal wells 2.5 m long and with a diameter of 76 to 105 mm drilled in the sides of underground mines with a bottom elevation of 2 ÷ 3 °.

The long-term practical application of the mountain pressure monitoring system “Prognoz ADS” in a number of enterprises has shown that one of the most actual tasks requiring solution at the projection stage is the task of optimal configuration of the underground observation network of receivers of acoustic signals.

The increase in the scale of the work performed in the controlled areas and the displacement of their front requires a gradual expansion of the controlled spatial zone, and, consequently, an increase in the number of seismic acoustic sensors to cover the required volume of the monitored array with the observation network. Therefore, as the number of geophones increases, the problem of choosing the optimal place for their installation is most acute.

2 Development of Methods for the Optimal Geophone Location

The construction of the optimal configuration of the observational network is a nontrivial task and requires consideration of many factors. However, the solution is greatly simplified with the introduction of a number of conventions and restrictions. In this case, it allows formulating methodological approaches to the optimal location of geophones in the first approach and to highlight directions for further improvement of developed approach.

Constructing the optimal configuration of the observational network provides for the choice of a location of geophones that would ensure the maximum possible volume of the zone of confident seismo acoustic signal recording. The choice of locations is proposed to be carried out on the basis of horizon plans since it is intended to deploy geophones at different horizons of the mine field and sensitivity maps of the observation network calculated for each horizon. They should take into account the existing mining and geological situation.

The algorithm for calculating the sensitivity map of the observational network is the main analytical algorithm for the optimal location method of geophones and provides for the calculation of the sensitivity coefficient for a spatial zone represented by a volume domain set of cubic form. Their size is allowed to customize.

The input information of the algorithm provides for the acquisition of the following data in a table form and abstract objects constructed on their basis (Fig. 1):

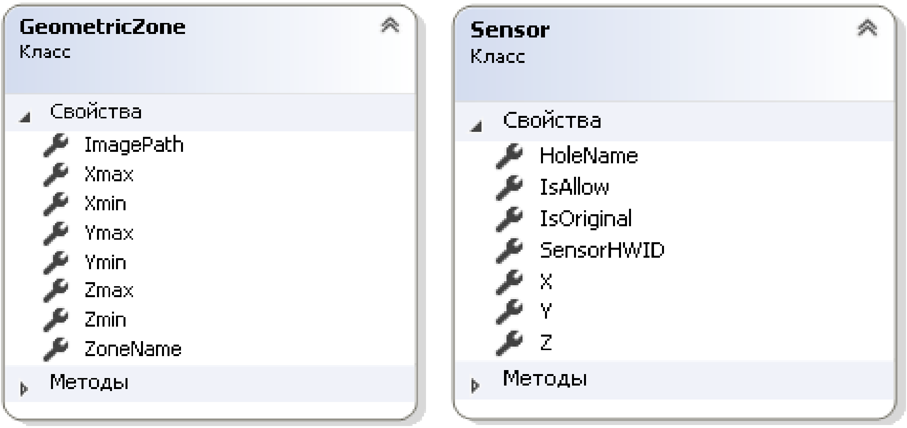
– sensitivity limit of a geophone is a scalar quantity. It characterizes the limiting value of the distance between the signal source and the geophone, at which the average useful seismo acoustic signal becomes indistinguishable at noise level;

– table of the location of the actually installed geophones;

– table of virtual geophones location;

– spatial zone characteristic table for building sensitivity map;

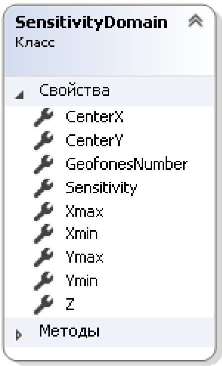
– graphic representations of plans for horizons of underground mines.



a) б)

Figure 1: Geometric zone (a) and geophone (b) models:
a) ImagePath – the absolute path to mine plan file; XMax, XMin, YMax, YMin, ZMax, ZMin – boundary point coordinates; ZoneName – spatial zone name;
б) HoleName – well number with primary converter installed; IsAllow – to take into account or not geophone in current calculation; IsOriginal – geophone state (set or added); SensorHWID – geophone serial number; X, Y, Z – geophone coordinates

Each of domains in spatial zone is an abstract object and is described by a set of properties that characterize its position in space, etc. (Fig. 2).



SensitivityDomain
Класс

Свойства
- CenterX
- CenterY
- GeofonesNumber
- Sensitivity
- Xmax
- Xmin
- Ymax
- Ymin
- Z

Методы

Figure 2: Domain model with a sensitivity characteristic of geophones:
CenterX, CenterY – center domain coordinates; GeofonesNumber – sensor number fixing this domain; Sensitivity – sensitivity; Xmax, Xmin, Ymax, Ymin, Z – domain boundary points coordinate

The algorithm for calculating sensitivity for each of domains of selected spatial zone is represented by the following steps:

1. The division of the spatial zone into domain regions of cubic form and their initialization;
2. Execution of a double cycle: external performs passage through the domains, internal - through geophones.

Following operations are performed at each iteration:

– calculation of the distance between domain center and sensor coordinates;

– increasing geophone counter, which can location event in a specific domain;

– increase in advance value of the relative sensitivity, if calculated in the previous operation distance is less than geophone sensitivity limit;

– zeroing domain sensitivity if geophone counter is insufficient (less than 4), or adjusting domain sensitivity parameter taking into account primary transducer number;

3. Removal of domains with zero sensitivity.

The value characterizing domain sensitivity is calculated using following formula:

$$s_0 = n \cdot \sum_{i=I}^{n}\left(1-\sqrt{D/r_{\text{Д}}}\right),$$

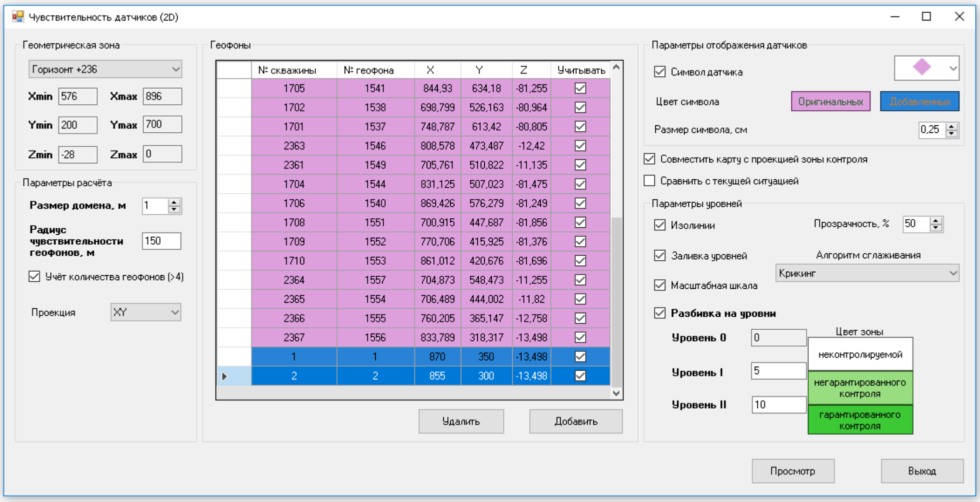
where n – geophone number detecting seismo acoustic event in the domain;

D – distance between domain center and sensor coordinates, m;

$r_{\text{Д}}$ – sensor sensitivity limit, m.

The developed algorithm is implemented in C # and integrated into the GeoAcoustics-ADS. It is seismic acoustic data processing and analysis software package, which is one of the most important components of the Prognoz ADS system.

Window of this program module is called from main menu of GeoAcoustics-ADS (Fig. 3).



Чувствительность датчиков (2D)

Геометрическая зона
Горизонт +236
Xmin 576 **Xmax** 896
Ymin 200 **Ymax** 700
Zmin -28 **Zmax** 0

Параметры расчёта
Размер домена, м 1
Радиус чувствительности геофонов, м 150
☑ Учёт количества геофонов (>4)
Проекция XY

Геофоны

№ скважины	№ геофона	X	Y	Z	Учитывать
1705	1541	844,93	634,18	-81,255	☑
1702	1538	698,799	526,163	-80,964	☑
1701	1537	748,787	613,42	-80,805	☑
2363	1546	808,578	473,487	-12,42	☑
2361	1549	705,761	510,822	-11,135	☑
1704	1544	831,125	507,023	-81,475	☑
1706	1540	869,426	576,279	-81,249	☑
1708	1551	700,915	447,687	-81,856	☑
1709	1552	770,706	415,925	-81,376	☑
1710	1553	861,012	420,676	-81,696	☑
2364	1557	704,873	548,473	-11,255	☑
2365	1554	706,489	444,002	-11,82	☑
2366	1555	760,205	365,147	-12,758	☑
2367	1556	833,789	318,317	-13,498	☑
1	1	870	350	-13,498	☑
2	2	855	300	-13,498	☑

Параметры отображения датчиков
☑ Символ датчика
Цвет символа: Оригинальных, Добавленных
Размер символа, см 0,25
☑ Совместить карту с проекцией зоны контроля
☐ Сравнить с текущей ситуацией

Параметры уровней
☑ Изолинии
Прозрачность, % 50
☑ Заливка уровней
Алгоритм сглаживания: Кригинг
☑ Масштабная шкала
☑ **Разбивка на уровни**

Уровень		Цвет зоны
Уровень 0	0	неконтролируемой
Уровень I	5	негарантированного контроля
Уровень II	10	гарантированного контроля

Figure 3: Software module interface for calculating domain sensitivity

The possibility of cooperative graphic display of sensitivity zone calculation results and mine plans is implemented for visual presentation.

Golden Software Surfer software is used as auxiliary visualization tools. It provides advanced features for visualizing data sets, including by running a script written in VisualBasic. Setting the script parameters is provided in developed module interface.

The sensitivity map display of spatial domain provides for two main modes.

Mode 1. This mode allows you to select a certain maximum value that characterizes limiting value of domain sensitivity parameter of mine or its area. Next, a user-preset color scheme is loaded that contains level set of percentages and their corresponding colors, represented in RGB model. Interpolation is performed on discrete set of sensitivity values based on specified parameters, during which intermediate color values are determined.

This mode is intended for:

– analysis of geophone distribution within zone boundaries;

– identify maximum sensitivity level, as well as the sensitivity levels of particular areas.

Current situation in one of controlled areas of mining enterprise with active mining operations, which was formed using gradient transitions in the first mode, is shown in Fig. 4.

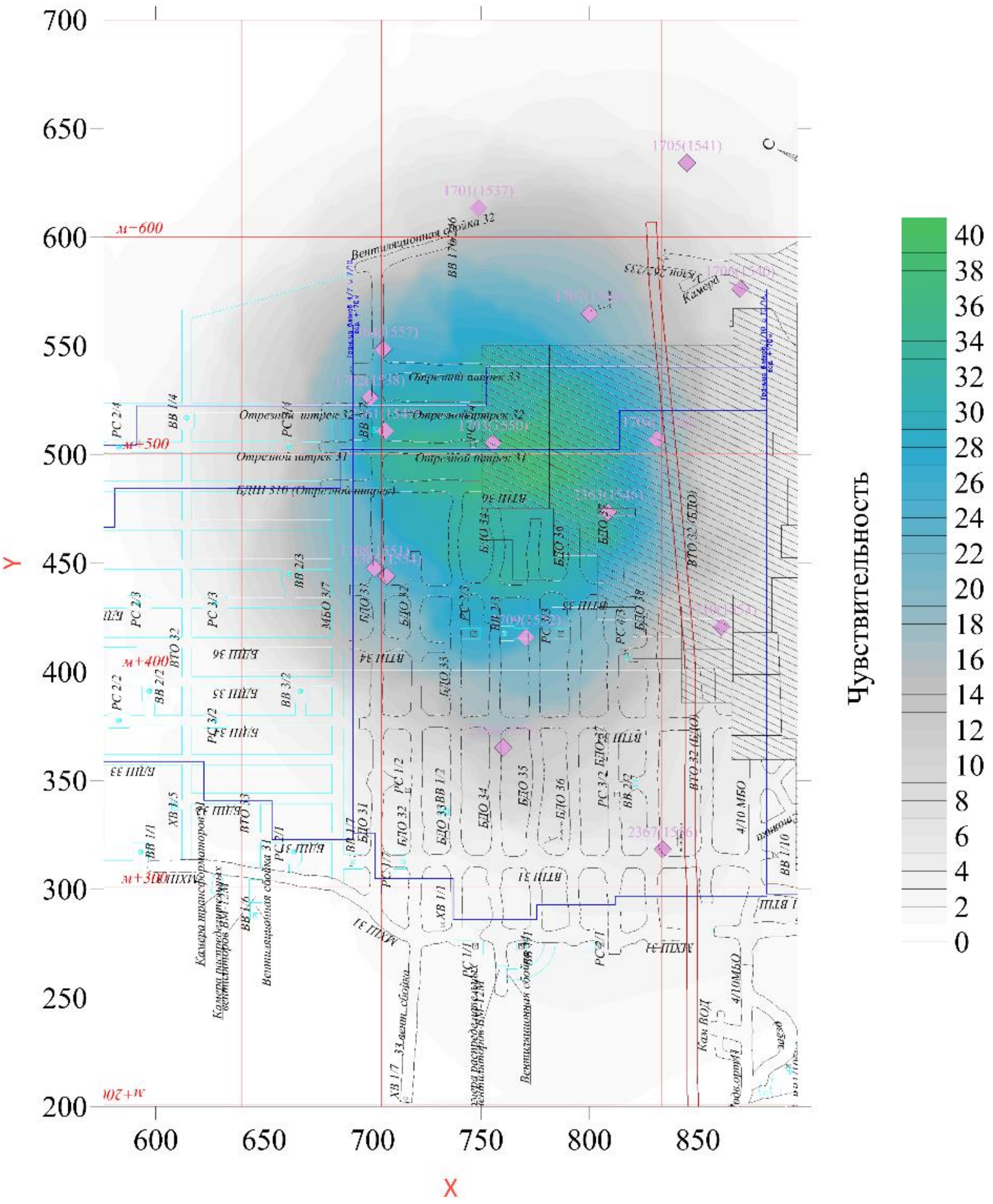


Figure 4: Example of domain sensitivity distribution obtained using of gradient levels

Mode 2. This mode is designed to divide entire geometric zone into 3 characteristic areas:

1. Uncontrolled area. Acoustic events can be located after improving the characteristics of geophones, or after increasing their number at a sufficient distance from source in this control zone;

2. Non-guaranteed control area. Acoustic events can be located with accuracy that is on limit of permissible technical characteristics of monitoring system in this control zone;

3. Zone of guaranteed control. Acoustic events can be located with accuracy according to technical characteristics of monitoring system and with sufficient veracity of their parametric description in this zone.

The plan of site control zone considered earlier is combined with a sensitivity map and is shown in figure 5 (mode 2). Gradient fill level values are selected empirically based on test data analysis and are 0, 5 and 15 units for the uncontrolled zone, the non-guaranteed control zone and the guaranteed control zone, accordingly.

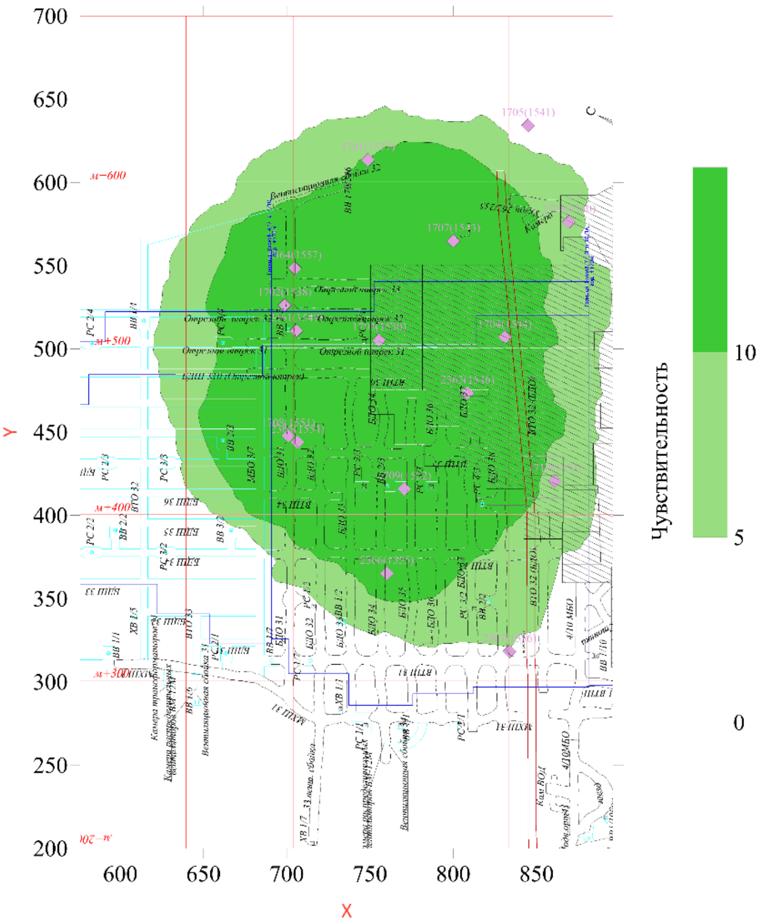


Figure 5: An example of domain sensitivity distribution, obtained using control levels

This mode allows you to:

– to split the research area into three separate zones;

– to make qualitative evaluation of efficiency of installed geophones;

– to check prone to shock hazard mine field areas for inclusion in the zone of confident location.

Following method is proposed for choosing number and placements of geophones and expanding controlled area in order to increase shock hazard control efficiency:

1. If the analysis is performed for the first time, it is necessary to use the first mode and define maximum sensitivity level. This limit will characterize the research area zone. Next, it is necessary to estimate the useful information loss about seismic events by conducting industrial test series, or by similar research on an adjacent region with similar mining and geological conditions. The maximum sensitivity reaches about 40 units for situation in Fig. 4. As an example, select following sensitivity levels of control zones:

– below 5 - uncontrolled zone;

– 5 - 10 - non-guaranteed control zone;

– above 10 - zone of guaranteed control

2. Monitored region coordinates are determined sequentially. Then they are checked for entry into the guaranteed control zone using the second mode. Take for testing point with coordinates 850, 350 from WTO 32 region (BDO). This region belongs to the non-guaranteed control zone, as follows from situation presented in Fig. 5.

3. The situation of sensitivity domain zone redistribution is simulated for each of the areas that do not meet the conditions of guaranteed control by addition, removal or movement of geophones. The final sensitivity map for the considered example after introduction of new geophones is shown in Fig. 6.

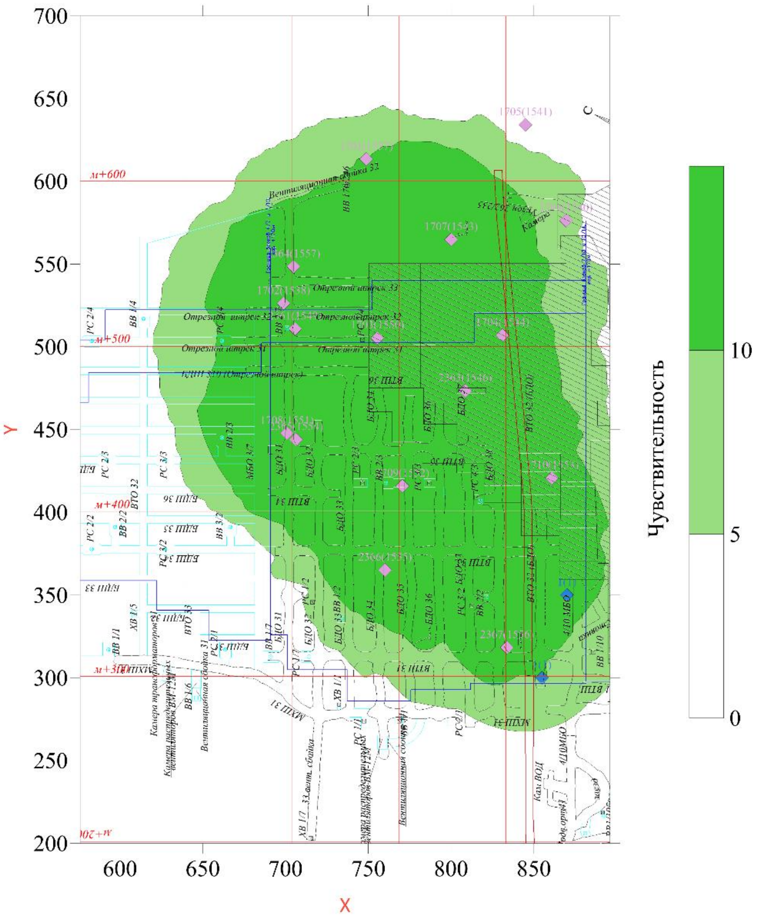


Figure 6: Sensitivity distribution after adding two sensors with coordinates 870, 350 and 855, 300.

It should be noted that possibility of installing geophones must be confirmed in the rock massif selected location on basis of enterprise technical conditions in each specific case.

3 Developed Model Limitations and Directions for Further Improvement

The proposed algorithm for constructing sensitivity maps for considered controlled zone and method for choosing the optimal installation geophone placements in mine field provide important practical problem to be solved. However, further improvement and modernization is required due to accepted limitations of design model. Let us consider some possible directions for further development of this approach.

1. Anisotropic rock massif properties.

Environment anisotropic properties, caused by physic mechanical properties of rocks and existence of empty spaces in seismic acoustic waves propagation analysis from the source to the geophone, should be taken into account [10, 11]. It is assumed that entire research area is composed of rocks and its environment is isotropic. Such statement greatly simplifies the design model. It requires creation of more advanced mathematical description of domains to solve this problem. For example, by using the velocity model created using results of experimental measurements.

2. Volumetric characteristics of receiving antennas.

The decrease in event location accuracy should be taken into account if it was recorded by geophones lying in plane (flat antenna) [12]. In such case, it is necessary to take into account flat antenna situation and prevent such sensor placements, or introduce additional sensitivity correction and characterizing antenna volume coefficient.

3. Automate optimal geophone placements.

It is necessary to change from manual selection of geophone installation places to automatic one, due to the subjective judgment of designing person. At initial stage, developed algorithm should allow the most efficient geophone installation in automatic mode. Then it is should consider possibility of selecting sensitivity levels for guaranteed and non-guaranteed control zones without user influence.

4. Use of three-dimensional domain sensitivity mathematical model.

It is proposed to use a two-dimensional geometric model of structure of the domain when calculating sensitivity maps in the developed method. This restriction is due to the existence of only flat plans for the mine field horizons. However, use of sufficient number of mine horizons plans for different elevations will allow to calculate pseudo-three-dimensional models with possibility of obtaining output information in volumetric representation. It is necessary to consider possibility of creating module that allows to interact with existing three-dimensional geometric models on controlled objects in order to obtain more complete and easy-to-understand information about controlled object.

4 Conclusion

The developed algorithm for constructing sensitivity maps allows one to get represent about geophone placement effectiveness in conditions of working seismic acoustic monitoring system, or to modeling zone parameters change in new configuration.

The developed method of selecting optimal location for installing geophones in mine field allows to formulate recommendations for optimal monitoring system monitoring zone extension based on model stages results of updated underground observation network configurations.

The directions for further improvement of proposed approach are formulated and options for a possible solution of model limitations are proposed.

The algorithm for constructing sensitivity maps for controlled zone and method of choosing optimal geophone installation placements in mine field allow analyzing sensitivity zones of seismo-acoustic monitoring system, provide detailed represent of influence of geophone location on monitoring zone spatial dimensions and suggest mathematical justification for optimal geophone location.

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