Результаты. По результатам экспериментальных исследований на лабораторной модели скважины построены графические зависимости кратности и устойчивости пены от определяющих параметров (типа и концентрации ПАВ и веществ-стабилизаторов и его температуры), по которым выбирали тип ПАВ и веществ-стабилизаторов, которые обеспечивают наибольшие значения кратности и устойчивости пены. С использованием методов математической статистики определяли оптимальные концентрации ПАВ и веществ-стабилизаторов пены, выше которых кратность и устойчивость пены изменяются мало. Разработаны две композиции ПАВ и веществ-стабилизаторов пены, одна из которых предназначается для промывки песчаных пробок на забое скважины, а другая – для непрерывного ввода в затрубное пространство скважины с целью предупреждения скопления твердой фазы на забое.

Научная новизна. На основе экспериментальных исследований установлены закономерности вспенивания водных растворов ПАВ без добавления и с добавлением веществ-стабилизаторов пены, разработан новый композиционный состав ПАВ и веществ-стабилизаторов для образования устойчивой пены с моделированием забойной температуры (от 20 до 60 °С).

Практическая значимость. Определены оптимальные значения концентраций пенообразующих ПАВ и веществ-стабилизаторов в водных растворах для получения устойчивых пен. Результаты исследований могут быть использованы для промывки песчаной пробки на забоях скважин на истощенных газовых и газоконденсатных месторождениях и предупреждения скопления твердой фазы на забое.

Ключевые слова: *вещества-стабилизаторы, кратность и устойчивость пены, модель скважины, пенообразование*

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MODELLING GEODETIC NETWORK TO IMPROVE RELIABILITY OF SURVEYING PROVIDING OF MINING OPERATIONS

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МОДЕЛЮВАННЯ ГЕОДЕЗИЧНОЇ ОСНОВИ ДЛЯ ПІДВИЩЕННЯ НАДІЙНОСТІ МАРКШЕЙДЕРСЬКОГО ЗАБЕЗПЕЧЕННЯ ГІРНИЧИХ РОБІТ

Purpose. The purpose of this work is to develop a model of a geodetic reference network (in the form of a transition graph), which is located on the territory of mining leases and is prone to disruption as a result of impact of man-made factors to improve the reliability of surveying maintenance of open and underground mining.

Methodology. To assess the state of geodetic framework using graph theory and stochastic processes the estimation of its reliability has been done. The analytical model of surveyor-geodetic network as a graph of conversions has been developed. The matrix of conditional distribution functions of duration of stay of the geodetic network in different states and matrix of transition probabilities from the previous state to the next has been complied. The average time of duration of stay of geodetic network in a reliable and unreliable state using semi-Markov process has been estimated.

Findings. The choice of mathematical model which describes the state of geodetic network in a particular time to the fullest extent possible has been substantiated. The length of stay of geodetic network in each of its possible fixed states has been determined.

Originality. The use of graph theory and stochastic processes to create a mathematical model of transitions of surveyor-geodetic network of a reliable state into an unreliable one as a result of displacement of rocks, the earth's surface and geodetic points located on it has been proposed for the first time. The duration of stay of the geodetic network in each of its possible fixed states has been determined. It allows carrying out a complex of works timely to restore geodetic network to ensure reliable surveying mining and experimental studies.

Practical value. The creation of a mathematical model of the geodetic network in the form of the transition graph by applying graph theory and semi-Markov process, allows identifying the time of decrease in reliability of geodetic

networks as a result of displacement of rocks under the influence of underground workings and its timely restoration up to reliable condition.

Keywords: *surveyor-geodetic network, semi-Markov process, graph theory, modeling*

Introduction. The performing surveying should provide completeness, accuracy and reliability of measurements and calculations for the rational use, protection of the natural resources, for safety of mining operations. When performing such a responsible surveying tasks as directly mining, which has been done by counter faces, the important role played by the assessment of the accuracy and the most likely reliability of measurement results. To solve such problems, we should use the theory of measurement errors, probability theory, graph and random processes theory, and also the NLSQ (Non-Linear Least Squares) method. When performing surveying the special attention needs to be paid to the geodesic network entry points which are replacing or destroying as a result of rocks shifting in the developed area.

The most important result of last century research in the field of geomechanics and geodynamics is revealing the close relationship between global and local geodynamic geomechanical processes resulting from man-made impact with mining array during the mining operations. Identifying the characteristics and destruction of means of forming an array of rocks, as a result of the nature of the earth's surface topography changes, deformations of buildings and engineering structures on it, could be achieved by integrated approach that includes theoretical analysis and experimental work using geodetic, geophysical and geomechanical methods. Reliability of results of experimental works directly depends on reliability of geodesic information.

Analysis of the recent publications. The analysis of the executed researches showed that a problem of estimation of reliability of geodesic network is an actual scientific task in our time. There are some devoted to this question domestic tractates by S. P. Voytenko, K. R. Tretyak, P. G. Chernyaha, Y. M. Kostetska, R. V. Shults, V. M. Gladilin, V. A. Vagin, Y. M. Vizirov, Y. I. Markuze, Y. V. Radionova, A. G. Alekseenko etc. And also by foreign scientists such as A. R. Amiri-Simkooei, W. Baarda, A. Uznañski, M. Kavouras.

In most scientific tractates domestic and foreign researchers were pointed internal reliability of geodetic network, which depends on the accuracy and network's configuration, comparison etc. While the stability, reliability and regularity of the fundamental geodetic points (exterior reliability) are equally important components in evaluating the reliability of geodetic network and should be taken into account. Assessing the reliability of geodetic network sometimes wonders when does it lost it, during what time it was reliable, what time does it take to get unreliable, others. Application of the graph theory and random processes will allow to identify the reliability loss and to restore it.

Analysis of the recent research. The problem of reliability assessment is not new, even in the 50s of the XIX century for the solution of that time technical problems, the creation of complex systems was required, for what were started the research in reliability field. Now the term "reliability" is used in all areas of human's life and attracts engineers, economists, mathematicians. According to research Kadigrob S. V. [1] to describe the operation of complex systems it is inappropriate to use Markov's methods because of possiblity of non-standard processes in their conditions. In Kadigrob's opinion [1] "when we get inaccurate values of the basic elements of semi-Markov's models (Matrix of conditional functions of duration distribution in their own possible conditions and matrix of transition's probability of Markov's chain, which are inserted to the semi-Markov's process) we are using the fuzzy sets theory namely semi-Markov's processes with not clearly defined parameters".

The difference between Semi-Markov's random process which has many different counted conditions and Markov's process is in the probability of transition from one condition to another depends on the length of time spent in the previous one.

The researches in field of the use of not clear semi-Markov's models are in many tractates that confirms actuality and perspective of researches direction. In Boyarinov's tractate [2] was offered semi-Markov's not clear model for a mining production, that allows to reduce the complexity of decision optimization problems In Boyarinov's U. G. opinion [2] "too frequent testing leads to the not completely use of the system, while rare testing of the system are responsible for the accumulation of fault elements of the system, which leads to not use the system too due to downtimes associated with its recovery". Regarding Mine Surveying and Geodesy this device allows science to justify holding periodic and reliable check of the elements (coordinate points) and system (geodetic and surveying network) and also make the remedial measures on time to help increase network reliability, which in turn will provide reliable surveying provision of mining works.

Unsolved aspects of the problem. The tasks of the reliability theory are the source of researches in the random processes theory. Especially widely used of semi-Markov processes gives an opportunity to describe functioning of many systems of reliability and get the row of important descriptions of these systems. Semi-Markov's processes are natural and important generalization of chains and processes of Markov, that allow more in detail to design the real systems in many branches of science and technology.

With appearance of new high-fidelity geodesic equipment and technologies, with the increase of complication of the systems and responsibility of executable tasks, a necessity appeared for the effective use, from the economic point of view, geodesic networks for the receipt of reliable results of geodetic and surveying works. Use of the geodetic reliable planning and altimetric survey network will allow to get reliable data of topographical survey of surface and surveys measurement of the open and underground mining and so on.

The objective. To assess the real state geodetic network and reliability providing survey mining operations, developed an analytical model of the functioning of the mine surveying and geodetic network based on graph theory and random processes and determined the length of stay of the geodetic network in each of its fixed position.

Presentation of the main research. When assessing the reliability of surveying and geodetic networks of any mining region it is necessary to choose an adequate model of its functioning at different intervals with possible transitions from one condition to another. This problem can be solved similarly to the solution given by the example of the geodetic network of Dnipro. In 2011 the state enterprise "Scientific-research Institute of geodesy and cartography" together with the Dnipropetrovsk branch of the Ukrainian state scientific-production Institute filming of cities and geo-Informatics named after A. V. Shah fulfilled a complex of geodesic works for further upgrading of urban geodetic network of Dnipro. The results of the works have been analyzed in [3]. The location of point centres in the city of Dnipropetrovsk was performed on topographic maps in the 1 : 10 000 to 1 : 100 000 scale range using external signs that remained on the ground, the external signs on the items, identifying pillars, the remnants of the external design, mounds or recesses over the centres etc. If necessary, the detection of points on the terrain was performed using navigation GPS receivers.

Field inspection of geodetic points included the following processes:

- searching for points on the site;
- visual examination of the centres and their external signs with a view to determining their state and appearance;
- reporting the results of the observations.

The point was regarded as lost when there were visual signs of its existing centre destruction (e. g. a capital building had been constructed in the place of the point, a mound had been destroyed, a pit had been dug, or the building had been destroyed), or when measures have been taken to detect the centre, including instrumental and geophysical methods yielded no positive result. The information about the surveyed points of the state geodetic network are given in Table 1.

The examination of urban points of the geodetic network was carried out in compliance with the current normative document [4] and Instruction [5].

The detection of point centres of the of first-order, second-order, third-order and fourth-order traverse and 1 and 2 discharges in urban areas was carried out using topographic maps in the 1 : 2000–1 : 10 000 scale range and rough sketches of traverse. Direct search for centres in the points of traverse on the spot was performed by linear measurements given in the rough sketches of traverse and by external features that were preserved on the terrain such as identification poles, traces of external design, metal caps or notches above the centres and the like. If necessary, the location of the points on the site was established using navigation GPS-receivers. Information about the surveyed points of the geodetic network of the city is presented in Table 2.

As of February 2013 geodetic fund consists of:

- the points of the state geodesic network 1–4 class – 162;
- the points of the urban polygon measurement 1–2 categories – 33;
- topographic plans of scale 1 : 5000 – 34;
- topographic plans of scale 1 : 2000 – 489;
- orthophoto scale 1 : 2000 – 568;
- plans scale 1:500 more than 500.

On the surveyed points of the state geodetic network (SGN) and on the points of triangulation of the city the satellite geodetic observations has been performed.

The point's coordinates (SGN) and urban triangulation have been calculated in State reference geodetic coordinate system USC-2000. The values of the average quadratic errors of the computed coordinates do not exceed 0.02 m. It should be noted that the level of abidance to the points of the state geodetic network points and urban polygon measurement today is about 60 %.

There are many examples in the history of mining and geodetic works of a reduction in the reliability of geodetic networks due to the fragility or poor sustainability of the centres and points of control. Therefore, the problem of long-term preservation and sustainability of survey stations is of great importance for surveying and geodetic production. Long-term preservation of centres and reference points can provide special constructive signs, materials and the choice of their locations. It seems much more difficult to ensure the invariability of the position of these signs since soils from the surface tend to become deformed causing a shift of signs. Therefore, it would be essential to monitor the coordinates of reference geodetic points periodically in order

Table 1

Statistics of the examined points of the state geodetic network of 1st, 2nd, 3rd, and 4th order in Dnipropetrovsk

Class	Type of sign	The number of points in which signs/centres are preserved (destroyed)	
		sign	center
1	pyramid	1	1
1	no external sign	1	1
2	pyramid	3 (1)	3
2	no external sign	2 (2)	2
3	pyramid	11 (6)	11 (1)
3 urban	pyramid	10 (6)	10 (2)
4 urban	pyramid	3 (1)	3

Table 2

Statistics of the surveyed points of the geodetic network of the city of Dnipropetrovsk

Type of center	The number of surveyed (destroyed) geodetic points		
	4th order	1st category	2nd category
U-15	–	2	6
U-15n	–	7	3
1	1 (1)	1	–
2	–	1	–
1 gr.	24 (14)	5 (4)	1
5 gr.	3 (3)	29 (18)	30 (6)
6 gr.	9 (5)	45 (11)	37

to assess their reliability and obtain reliable geodetic data. The structure of the factors of influence on the reliability of geodetic networks is presented in Fig. 1.

Periodicity of control t of position of initial stations of geodetic network in terms of specified displacement intensity and specified probability of rigidity of position of geodetic stations can be identified with the help of equation of exponential distribution of random value $P(t) = e^{-\lambda t}$, from which we have

$$t = -\frac{\ln P(t)}{\lambda}.$$

To select stable stations of geodetic network, possible error intervals to determine their coordinates (Table 3) have been calculated according to the statistical formula

$$\bar{x} - t\left(\frac{\sigma}{\sqrt{n}}\right) \le X \le \bar{x} + t\left(\frac{\sigma}{\sqrt{n}}\right),$$

where $t\left(\frac{\sigma}{\sqrt{n}}\right) = \delta$ is estimation accuracy; "X" is localization error; $\bar{x}$ is a mean sample; "n" is sample volume; "σ" is a mean square deviation of coordinates of geodetic stations; "t" is argument value of Laplace's function $\Phi(t)$ $\Phi(t) = \gamma/2$; and "γ" is reliability.

It follows from Table 1 data that in terms of reliability objective, the stability of geodetic stations of corresponding accuracy class is determined with the help of probability intervals of errors while positioning. A station is supposed as unstable if positioning error goes beyond the probability interval [6].

Analysis of studies [7] has shown that application of satellite approaches is efficient in the context of considerable displacement rates (more than 30 mm per annum) when demands for determination accuracy are bated. In the context of insignificant displacement rates

Table 3

Error intervals of geodetic stations positioning [6]

Network group	Reliability		
	0.9	0.95	0.99
	Error intervals of positioning, mm		
1	2.88–3.12	2.86–3.14	2.82–3.18
2	19.85–20.15	19.82–20.18	19.76–20.99
3	31.79–32.21	31.75–32.25	31.67–32.33
4	31.76–32.24	31.72–32.28	31.63–32.37

(3–10 mm per annum) it is required to lengthen intervals between observational cycles considerably. If accuracy of displacement determination is not satisfactory then optimum traditional technique is applied or measuring GPS-based technique is changed.

Consider the sequence of loss of reliability of a system. Under the system we mean the geodetic network, that includes a certain number of elements, which we will consider as geodesic points. At any given time, the system can be in only one of two conditions: reliable (E) or unreliable (E^*). So let's analyze the process of transitions surveying-geodetic network (system) from one state to another of any mining region (Fig. 2).

According to the Fig. 2 basic surveying-geodetic network at the initial moment of time is in a reliable position S_1 (the probability of constant position of geodetic points is $P \ge 0.9$). Element or system transiting to the position of diagnosing the S_3 with probable transition of establishment $p_{13} = 1$. According to the results of the diagnosis: the geodetic network can move to an unreliable state S_2 ($P < 0.9$) with transition probability $p_{32} = Q$ (loss of reliability), or to stay in a reliable state S_1 with a transition probability $p_{31} = 1 - Q$. To restore the normal functioning of the element or system in an unreliable condition S_2 the procedure S_4 should be done (a com-

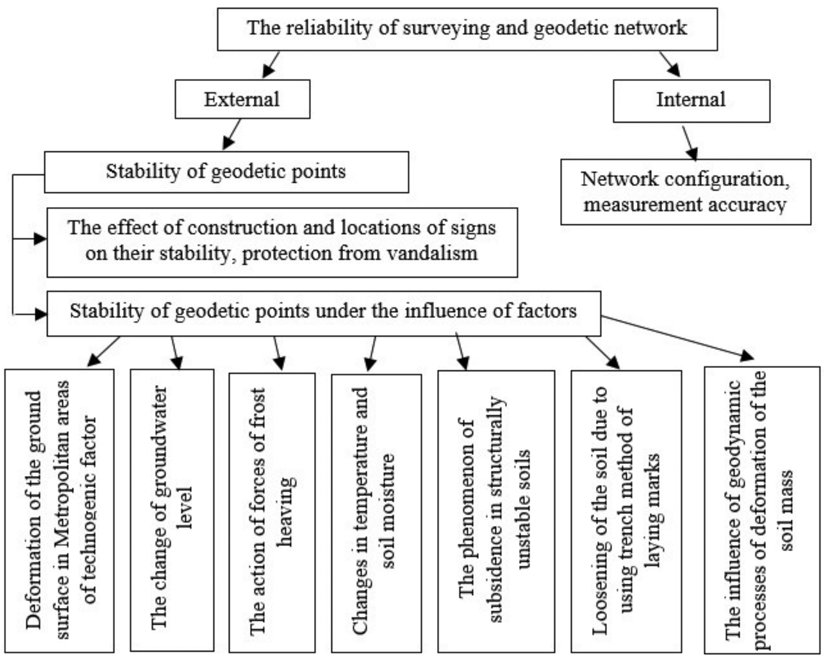

Fig. 1. The structure of the factors influencing the reliability of surveying and geodetic network

plex of rehabilitation works or reconstruction of the network) with probability of transition $p_{41} = 1$ in state S_1.

For description of the possible conditions of the systems (Fig. 2) Need to compose the matrices of conditional functions of distribution of duration of stay $F(t)$ of network in the different states and matrix of probability of transitions from the previous condition to the following

$$F(t) = \begin{pmatrix} 0 & 0 & F_{13} & 0 \\ 0 & 0 & 0 & F_{24} \\ F_{31} & F_{32} & 0 & 0 \\ F_{41} & 0 & 0 & 0 \end{pmatrix}; \quad p = \begin{pmatrix} 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1-Q & Q & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}. \qquad (1)$$

In accordance with Fig. 2 the components of matrix F(t) look like

$$F_{13}(t) = \begin{cases} 0, t \le 0 \\ \dfrac{F_{n.f.}(T_d) - F_{n.f.}(T_d - t)}{F_{n.f.}(T_d)}, \quad 0 < t < T_d; \\ 1, t \ge T_d \end{cases}$$

$$F_{31}(t) = \begin{cases} 0, t < T_d \\ 1, t \ge T_d \end{cases}; \quad F_{32}(t) = \begin{cases} 0, t \le 0 \\ \dfrac{F_{l.r.}(t)}{F_{l.r.}(T_{l.r.})}, \quad 0 < t < T_{l.r.}; \\ 1, t \ge T_{l.r.} \end{cases}$$

$$F_{24}(t) = \begin{cases} 0, t < T_{r.} \\ 1, t \ge T_{r.} \end{cases}; \quad F_{41}(t) = \begin{cases} 0, t < T_{n.f.} \\ 1, t \ge T_{n.f.} \end{cases},$$

where "t" is time of stay of element or system in the condition S_i, if next position of an element or system will be position S_j; $F_{n.f.}$ is a function of distribution of time of the normal functioning of element or system; $T_{d.}$ is the mathematics expected value of duration of diagnosticating of element or system; $T_{l.r.}$ is the value of mathematic expected duration of loss of reliability of element or system; $T_{r.}$ is the value of mathematic expected duration of restoring of an element or system; $T_{n.f.}$ is a period of the normal functioning of geodesic network (a network is in the reliable condition of S_1); $F_{l.r.}$ is a function of distribution of random value of $T_{l.r}$ of the moment of origin of instability of geodesic points.

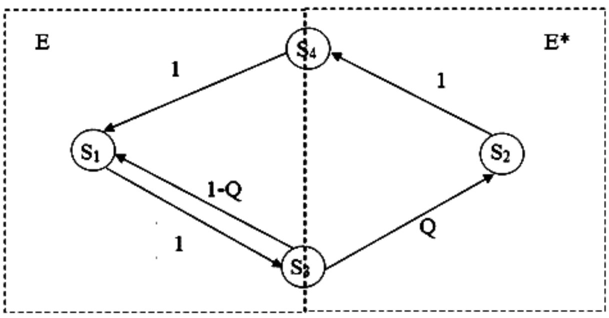

Fig. 2. Graph of transitions of elements (geodesic points) or system (mine surveyor-geodesic network):

E – reliable condition of the system; E – unreliable condition of the system; S_1 – reliable condition of elements; S_2 – unreliable condition of elements; S_3 – condition of diagnosticating of elements; S_4 – condition of elements restore; Q – probability of reliability loss*

The functions of distribution of duration of stay $F_i(t)$ of geodesic network in the different conditions (Fig. 2) determine by expression

$$F_i(t) = \sum_{j=1}^{4} F_{ij}(t) p_{ij}; \qquad (2)$$

$$F_1(t) = \begin{cases} 0, t \le 0 \\ F_{d.}(t), 0 < t < T_{d.}; \\ 1, t \ge T_{d.} \end{cases}$$

$$F_2(t) = F_{24}; \quad F_3(t) = F_{31} + F_{32}; \quad F_4(t) = F_{41},$$

where F_d. is a function of distribution of time of diagnosticating of element or system.

Mean time of stay of the system in the corresponding conditions is determined by expression

$$T_i = \int_0^\infty \left[1 - F_i(t)\right] dt; \qquad (3)$$

$$T_1 = \int_0^\infty \left[1 - F_1(t)\right] dt = T_{l.r.} - \int_0^{T_П} F_{l.r.}(t) dt; \quad T_2 = T_{r.};$$

$$T_3 = \frac{1}{F_{l.r.}(T_{d.})} \int_0^{T_K} F_{l.r.}(T_{d.} - t) dt; \quad T_4 = T_{n.f}.$$

Thus, application of semi Markov processes at the estimation of reliability of the mine surveyor-geodesic network allows to create the model of network's transitions from one condition to another, and also calculate time of the transition.

Conclusions and recommendations for further research. The given analytical model of functioning of the system in a kind of a graph of transitions can be applied for the estimation of reliability of the mine surveyor-geodetic networks that are located on territory of conduct of mining works, and also geodetic control networks, for works of national inventory in mining industrial regions. Timely determination of the condition of loss of reliability of networks based on results the repeated control of coordinates of geodesic points and implementation of complex of works on their restore will allow to promote exactness and quality of conduct of mine surveyor, geodetic and cadastre operations with the receipt of reliable results. The use of the reliable mine surveyor-geodetic basis will allow to promote exactness of determination of the areas of the concessions and their taxation, the exactness of determination of mineral supplies in storages, area and volume of ash disposal area others like that.

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Мета. Розробка моделі функціонування геодезичної опорної мережі (у вигляді графу переходів), розташованої на території гірничих відведень, що схильна до порушення в результаті впливу техногенного чинника, для підвищення надійності маркшейдерського забезпечення відкритих і підземних гірничих робіт.

Методика. Для оцінки стану геодезичної основи виконана оцінка її надійності із застосуванням теорії графів і випадкових процесів. Розроблена аналітична модель функціонування маркшейдерсько-геодезичної мережі у вигляді графу переходів. Складена матриця умовних функцій розподілу тривалості перебування геодезичної мережі в різних станах і матриця ймовірності переходів із попереднього стану в наступний. Визначено середній час перебування геодезичної мережі в надійному та ненадійному стані з використанням напівмарківського процесу.

Результати. Обгрунтовано вибір математичної моделі, що найбільш повно описує стан геодезичної мережі в конкретний момент часу, а також визначена тривалість перебування геодезичної мережі в кожному з її можливих фіксованих станів.

Наукова новизна. Уперше запропоноване використання теорії графів і випадкових процесів для створення математичної моделі переходів маркшейдерсько-геодезичної мережі з надійного стану в ненадійний у результаті зрушень гіських порід, земної поверхні та геодезичних пунктів, розташованих на ній. Визначена тривалість перебування геодезичної мережі в кожному з її фіксованих станів, що дозволяє своєчасно виконати комплекс робіт з її відновлення для надійного маркшейдерського забезпечення гірничих робіт та експериментальних досліджень.

Практична значимість. Створення математичної моделі функціонування маркшейдерсько-геодезичної мережі у вигляді графу переходів на основі застосування теорії графів і напівмаркіського процесу дозволяє виявити момент зниження надійності мережі в результаті зрушень гірськх порід під впливом підземних розробок і своєчасно виконати її відновлення до надійного стану.

Ключові слова: *маркшейдерсько-геодезична мережа, напівмарківський процес, теорія графів, моделювання*

Цель. Разработка модели функционирования геодезической опорной сети (в виде графа переходов), расположенной на территории горных отводов, которая склонна к нарушению в результате воздействия техногенного фактора, для повышения надежности маркшейдерского обеспечения открытых и подземных горных работ.

Методика. Для оценки состояния геодезической основы выполнена оценка ее надежности с применением теории графов и случайных процессов. Разработана аналитическая модель функционирования маркшейдерско-геодезической сети в виде графа переходов. Составлена матрица условных функций распределения продолжительности пребывания геодезической сети в различных состояниях и матрица вероятности переходов из предыдущего состояния в следующее. Определено среднее время пребывания геодезической сети в надежном и ненадежном состоянии с использованием полумарковских процессов.

Результаты. Обоснован выбор математической модели, которая наиболее полно описывает состояние геодезической сети в конкретный момент времени, а также определена продолжительность пребывания геодезической сети в каждом из ее возможных фиксированных состояний.

Научная новизна. Впервые предложено использование теории графов и случайных процессов для создания математической модели переходов маркшейдерско-геодезической сети из надежного состояния в ненадежное в результате сдвижения горных пород, земной поверхности и геодезических пунктов, расположенных на ней. Определена продолжительность пребывания геодезической сети в каждом из ее возможных фиксированных состояний, которая позволяет своевременно выполнять комплекс работ по ее восстановлению для надежного маркшейдерского обеспечения горных работ и экспериментальных исследований.

Практическая значимость. Создание математической модели функционирования маркшейдерско-геодезической сети в виде графа переходов на основе применения теории графов и полумарковского процесса позволяет выявить момент снижения надежности сети в результате сдвижения горных пород под влиянием подземных разработок и своевременно выполнить ее восстановление до надежного состояния.

Ключевые слова: *маркшейдерско-геодезическая сеть, полумарковский процесс, теория графов, моделирование*

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