З використанням розроблених математичних моделей реакції комплексу охоронної сигналізації на появу рухомого об'єкта показана залежність його ефективності від кількості сейсмічних датчиків і схеми їх розміщення на ймовірних маршрутах пересування. В дослідженнях враховано, що ефективність комплексу визначають чутливість сейсмічних датчиків та параметри його систем: ймовірність правильної класифікації рухомих об'єктів та ймовірність правильного приймання радіосигналу

Ключові слова: комплекс охоронної сигналізації, сейсмічні датчики, математична модель комплексу охоронної сигналізації

Используя разработанные математические модели реакции комплекса охранной сигнализации на появление движущегося объекта, показана зависимость его эффективности от количества сейсмических датчиков и схемы их размещения на вероятных маршрутах передвижения. В исследованиях учтено, что эффективность комплекса определяют чувствительность сейсмических датчиков и параметры его систем: вероятность правильной классификации движущихся объектов и вероятность правильного приема радиосигнала

Ключевые слова: комплекс охранной сигнализации, сейсмические датчики, математическая модель комплекса охранной сигнализации

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RESEARCH OF THE DEPENDENCE OF THE GUARD SIGNALING COMPLEX ON THE LOCATION OF SEISMIC SENSORS

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1. Introduction

In the practice of using guard signaling complexes there are the following layouts of the location of seismic sensors (SS) on the possible movement routes of moving objects (MO): four SSs placed in pairs if far and close control zones; two SS_S placed on the border in far or close control zones; two SS_S placed serially in far and close control zones; one SS placed in far or close control zone.

The effectiveness of GSC depends not only on SS sensitivity but also on the possibilities of the method of MO classification and the way of transmitting over radio channel from autonomous systems of detection, object classification and transmitting radio signals (DOCTRS) to the systems of receiving and displaying information (RDI) of GSC.

In order to research the dependence of the GSC effectiveness on SS location and receive recommended parameters for autonomous systems DOCTRS and RDI it is necessary to develop mathematical models which could allow comparative analysis.

Model of GSC reaction for two SS_S located serially in far and close control zones is given in articles [1, 2].

In the given article the authors present a mathematical model of GSC reaction on the MO appearance with SS_S placed in pairs in far and close control zones.

Using these models the research has been conducted of the GSC effectiveness for two ways of SSs location. In addition, one model was used to conduct research of GSC effectiveness with one SS on the route, and the second one – for two SS_S placed on the border.

The authors received and analysed dependences of probability of successful carrying out of GSC task on the probability of correct MO classification, probability of correct radio signal receiving and probability of SS reaction on MO. Probability of SS reaction on MO represents its sensitivity, takes into account characteristics of the area (ground, relief), season of the year, and MO parameters.

2. Analysis of researches and publications

Problems as for creation of the guard signaling system are considered in the publications [1 – 9].

The articles [3, 4] describe existing radio electronic guard systems. Radio electronic guard networks are presented among others in which seismic sensors are used (SS). It is determined that seismic electronic magnetic networks are widely used for guarding warehouses with nuclear weapons. They provide detecting a trespasser who walks or crawl slowly. Intelligence signal systems which have SS_S in their structure are used for rapid installing of guard systems. Seismic sensors also have guard systems along the perimeter.

The article [5] considers the method of autonomous blocks for creating adaptive algorithms of the detecting of the moving objects (MO). This method allows to model the process of propagation of seismic waves. The research that is being carried aims to examine the peculiarities of formation and propagation of seismic waves on the ground, the influence of the SS characteristics on the formation of signals.

Guard signaling systems have to process seismic signal in order to detect and classify MO in real time. In the article [6] this task is solved by the method of express evaluation of the spectrum characteristics of seismic signals on the base of their extreme filtration. The authors confirm that this method of evaluation of spectrum characteristics is effective, simple and not requiring the expenditure of much labour. Parameters of constituents allow to form diagnostic signs with necessary characteristics, namely, to have physical interpretation, to describe certain characteristics of the signal; to be stable (not to be changed during insignificant change of the signal characteristics); to be computed in real time.

The article [7] considers the development of guard systems for the territories and objects of strategic importance. It solves the task of compatible processing of seismic, acoustic and magnetometric signals that come from the sensors. For the complex analysis of the received information it is suggested to use the algorithm the basis of which is method of combinatorial ordered modelling. This method allows to carry out the possibility of self-learning in the process of detection and recognition of MO, and also to reduce the quantity of false alarms from GSC.

In the reference book [8] there is a model with the aid of which you can present the reaction of GSC on the movement of the object through the controlled area. However, the degree of the adequacy of such model does not allow differentially present such peculiarities as detecting by the seismic sensor the appearance of the MO in the controlled zone, successful classification of the MO, correct receiving of the radio signals of RDI (Receiving and Displaying information).

In order to research the effectiveness of GSC in the articles [1, 2] it is suggested to use the mathematical model of the reaction of GSC on the movement of the MO in the distant and close zones of control. Two SSs are installed serially along the route.

In the thesis research [9] the following models are suggested: mathematical models of the analysis of space organizational structure of the object under guard and models of making project decisions during development of technical means complex.

So, in well-known publications about GSC effectiveness, the main attention is given to the development and improvement of the methods of MO classification. There is one more possibility to improve GSC effectiveness – due to the rational placement of seismic sensors.

The aim of the work is to develop a mathematical model of GSC reaction on the appearance of MO with pairwise placement of SSs in far and close control zones in order to conduct research of the dependence of GSC effectiveness on the SS sensitivity, on the effectiveness of the method of MO classification, and on the effectiveness of the radio signal transmitting system.

3. Mathematical model of guard signaling complex on the appearance of moving object

Guard signaling complex detects MO with the aid of SSs of autonomous systems DOCTRS, classification device identifies it, and the transmitter of the autonomous system transmits radio signal to RDI about the type of MO.

Effectiveness of such complex depends on SSs placement of autonomous systems DOCTRS, on their sensitivity, method of MO classification, system of transmitting radio signals. This dependence stipulates necessary degree of adequacy of a mathematical model of GSC reaction on the MO appearance with pairwise placement of SSs in far and close control zones.

The model gives possibility to research optimal structure and technical characteristics of the equipment that will be used under different conditions of its installment [1, 2].

Guard signaling complex is to be installed on probable routes of unauthorized MO movement to stationary object (SO) (Fig. 1). In this research the following variant of installing autonomous systems DOCTRS is examined: in far and close borders there are two by two autonomous systems $DOCTRS_1$ and $DOCTRS_2$, $DOCTRS_3$ and $DOCTRS_4$, thus creating appropriate control zones. Zones of SSs sensitivity of each pair border each other. Such variant gives possibility to determine the direction of MO movement.

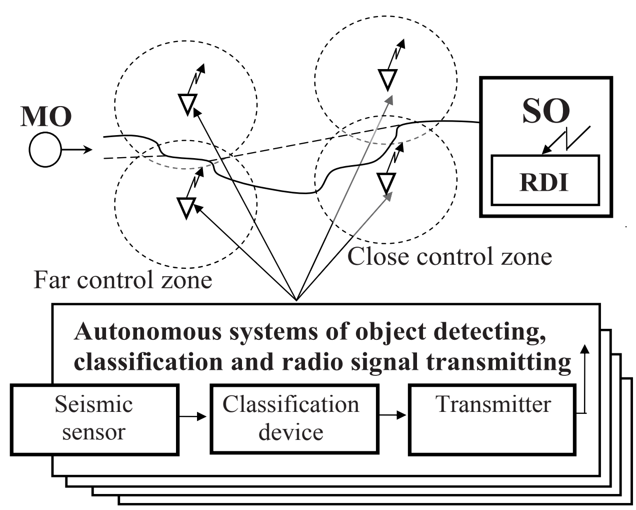

Fig. 1. Layout of placement of GSC systems

Technology of modeling discrete continuous stochastic systems [10, 11] was used to create mathematical model. It provides for the formation of the model in the form of graph of state and transitions and compiling system of differential equations of Kolmogorov – Chapman [8].

Method of development of the graph of state and transitions is the development of formalized presentation of the object under research in the form of structural automation model (SAM). This process on the base of SAM is formalized and is carried out with the aid of software module ASNA-1.

Components of SAM are as follows:

1) parameters of the object under research that are included into its mathematical model;

2) state vector of the object under research;

3) basic events (BE);

4) formalized description of the situations in which BE_S take place (conditions and circumstances taken into attention fot the given BE);

5) formulae of evaluation of the intensity of basic events for each situation in which BE takes place;

6) rules of modification of state vector component.

Parameters of SS reaction of autonomous systems $DOCTRS_{1,2,3,4}$ *on MO appearance* (they are determined with a glance of soil type, relief, distance of MO from SS, weight and speed of MO):

P_1 (P_2) – probability that both SSs of autonomous systems DOCTRS1 and DOCTRS2 do not react (react) on the MO appearance in far control zone;

P_3 (P_4) – probability that SS of autonomous system $DOCTRS_1$ does not react (reacts) on MO, and SS of autonomous system $DOCTRS_2$ reacts (does not react) on MO when it appears in far control zone;

P_{13} (P_{14}) – probability that both SSs of autonomous systems $DOCTRS_3$ and $DOCTRS_4$ do not react (react) on the MO appearance in close zone of control;

P_{15} (P_{16})–probabilitythatSSofautonomoussystem $DOCTRS_3$ does not react (reacts) on MO, and SS of autonomous system $DOCTRS_4$ reacts (does not react) on MO, when it appears in close zone of control.

Parameters of classification devices of autonomous systems $DOCTRS_1, DOCTRS_2, DOCTRS_3$ and $DOCTRS_4$.

As far as SS_S of autonomous systems DOCTRS are installed in different soil, results of a correct determination of MO type will differ :

P_5 (P_6) – probability that classification device of autonomous system $DOCTRS_1$ determines MO type incorrectly (correctly);

P_7 (P_8) – probability that classification device of autonomous system $DOCTRS_2$ determines MO type incorrectly (correctly);

P_{17} (P_{18}) – probability that classification device of autonomous system $DOCTRS_3$ determines MO type incorrectly (correctly);

P_{19} (P_{20}) – probability that classification device of autonomous system $DOCTRS_4$ determines MO type incorrectly (correctly).

As far as SS_S of autonomous systems DOCTRS are installed on the area under different conditions (distance from RDI, use of different antennas), results of receiving radio signals RDI from autonomous systems DOCTRS might be different:

P_9 (P_{10}) – probability that RDI receives (does not receive) a radio signal from $DOCTRS_1$;

P_{11} (P_{12}) – probability that RDI receives (does not receive) a radio signal from $DOCTRS_2$;

P_{21} (P_{22}) – probability that RDI receives (does not receive) a radio signal from $DOCTRS_3$;

P_{23} (P_{24}) – probability that RDI receives (does not receive) a radio signal from $DOCTRS_4$.

State of the object under research is presented by a vector that has 7 component providing necessary degree of model adequacy, namely:

– Component V_1 presents the location of MO on the area and can acquire the following values: $V_1 = 1$ – MO beyond the sensitivity zone SS_1, SS_2, SS_3 and SS_4 ; $V_1 = 2$ – MO in far control zone (zones of sensitivity SS_1 1 and SS_2); $V_1 = 3$ – MO in close control zone (zones of sensitivity SS_3 and SS_4). Initial value $V_1 = 1$.

– Component V_2 presents state of autonomous system $DOCTRS_1$ (characterizes interaction of autonomous systems $DOCTRS_1$ with MO). Values of this component: $V_2 = 0$ – autonomous system $DOCTRS_1$ is in good order and ready to work, MO is absent in sensitivity zone SS_1; $V_2 = 1$ – autonomous system $DOCTRS_1$ does not react on MO location in sensitivity zone SS_1; $V_2 = 2$ – autonomous system $DOCTRS_1$ reacts on MO location in sensitivity zone SS_1, but does not classify it correctly; $V_2 = 3$ – autonomous system $DOCTRS_1$ reacts on MO location in sensitivity zone SS_1 and classifies it correctly. Initial value $V_2 = 0$.

– Component V_3 presents state of autonomous system $DOCTRS_2$ (characterizes the reaction of autonomous system $DOCTRS_2$ on MO). Value of this component: $V_3 = 0$ – autonomous system $DOCTRS_2$ is in good order and ready to work, MO is absent in sensitivity zone SS_2; $V_3 = 1$ – autonomous system $DOCTRS_2$ does not react on MO location in sensitivity zone SS_2; $V_3 = 2$ – autonomous system $DOCTRS_2$ reacts on MO location in sensitivity zone SS_2, but does not classify it correctly; $V_3 = 3$ – autonomous system $DOCTRS_2$ reacts on MO location in sensitivity zone and classify it correctly. Initial value $V_3 = 0$.

– Component V_4 presents state of autonomous system $DOCTRS_3$. Values of this component: $V_4 = 0$ – autonomous system $DOCTRS_3$ is in good order and ready to work, MO is absent in sensitivity zone SS_3; $V_4 = 1$ – autonomous system $DOCTRS_3$ does not react on MO location in sensitivity zone SS_3; $V_4 = 2$ – autonomous system $DOCTRS_3$ reacts on MO location in sensitivity zone SS_3, but does not classify it correctly; $V_4 = 3$ – autonomous system $DOCTRS_3$ reacts on MO location in sensitivity zone and classifies it correctly. Initial value $V_4 = 0$.

– Component V_5 presents state of autonomous system $DOCTRS_4$. Values of this component: $V_5 = 0$ – autonomous system $DOCTRS_4$ is in good order and ready to work, MO is absent in sensitivity zone SS_4; $V_5 = 1$ – autonomous system $DOCTRS_4$ does not react on MO location in sensitivity zone SS_4; $V_5 = 2$ – autonomous system $DOCTRS_4$ reacts on MO location in sensitivity zone SS_4, but does not classify it correctly; $V_5 = 3$ – autonomous system DOCTRS4 reacts on MO location in sensitivity zone SS_4 and classifies it correctly. Initial value $V_5 = 0$.

– Component V_6 presents state of RDI, when MO is in far control zone (sensitivity zones SS_1 and SS_2). Values of component V_6: $V_6 = 0$ – RDIS is on in standby condition; $V_6 = 1$ – RDI is activated from radio signal of autonomous system $DOCTRS_1$; $V_6 = 2$ – RDI is not activated from radio signal of autonomous system $DOCTRS_1$; $V_6 = 3$ – RDI is activated from radio signal of autonomous system $DOCTRS_2$; $V_6 = 4$ – RDI is not activated from radio signal of autonomous system $DOCTRS_2$; $V_6 = 5$ – RDI is activated from radio signals of autonomous systems $DOCTRS_1$ and $DOCTRS_2$; $V_6 = 6$ – RDI is not activated from radio signals of autonomous systems $DOCTRS_1$ and $DOCTRS_2$; $V_6 = 7$ – RDI is activated from radio signal of autonomous system $DOCTRS_1$ but is not activated from radio signal of autonomous system $DOCTRS_2$; $V_6 = 8$ – RDI is activated from radio signal of autonomous system $DOCTRS_2$ but is not activated from radio signal of autonomous system $DOCTRS_1$. Initial value $V_6 = 0$.

– Component V_7 presents state of of RDI, when MO is in close control zone (zones of sensitivity SS_3 and SS_4) and may acquire the following values: $V_7 = 0$ – RDI is on and in standby condition; $V_7 = 1$ – RDI is activated from radio signal of autonomous system $DOCTRS_3$; $V_7 = 2$ – RDI is not activated from radio signal of autonomous system $DOCTRS_3$; $V_7 = 3$ – RDI is activated from radio signal of autonomous system $DOCTRS_4$; $V_7 = 4$ – RDI is not activated from radio signal of autonomous system $DOCTRS_4$; $V_7 = 5$ – RDI is activated from radio signals of autonomous systems $DOCTRS_3$ and $DOCTRS_4$; $V_7 = 6$ – RDI is not activated from radio signals of autonomous systems $DOCTRS_3$ and $DOCTRS_4$; $V_7 = 7$ – RDI is activated from radio signal of autonomous system $DOCTRS_3$ but is not activated from radio signal of autonomous system $DOCTRS_4$; $V_7 = 8$ – RDI is activated from radio signal of autonomous system $DOCTRS_4$ and is not activated from radio signal of autonomous system $DOCTRS_3$. Initial value $V_7 = 0$.

Basic events (BE) in the object under research are as follows:

– end of MO location beyond far control zone (MO appearance in sensitivity zone of SS_1 and SS_2) (BE1). This BE1 is combined with basic events CBE3 – "End of reaction of SS_1 on the MO appearance", CBE4 – "End of SS_2 reaction on MO appearance", CBE5 – "End of receiving of RDI radio signal from autonomous system $DOCTRS_2$".

– end of MO location in far control zone (MO appearance in sensitivity zone of SS_3 and SS_4) (BE2). This BE is combined with basic events CBE7 – "End of SS_1 reaction on MO appearance", CBE8 – "End of SS_4 reaction on MO appearance", CBE9 – "End of receiving RDI radio signal from autonomous system $DOCTRS_4$".

The basic event that finishes carrying out corresponding procedure with the duration that tends to zero is called combined basic event (CBE). A tree of modification rules state vector component is built on the determined BEs and serves as a basis for building a model of the object under research in the form of graphs of states and transitions.

During development of the tree of modification rules state vector component the following tasks are solved: formalized description of situations when BEs take place is given; formulae of calculation of basic events intensity (FCBEI) are composed (in these formulae λ_1, λ_2 – intensity of MO appearance in far and close control zones respectively); modification rules state vector component (MRSVC) are established. The tree MRSVC is given in Table 1, 2.

Table 1

Tree of modification rules state vector component for BE1

BE1: End of MO location beyond far control zone (MO appearance in sensitivity zone of SS_1 and SS_2) (CBE3, CBE4, CBE5, CBE6)	
Description of situation when BE1takes place: V_1=1	
FCBEI	MRSVC
1	2
$\lambda_1 \cdot P_1$	$V_1 := 2; V_2 := 1; V_3 := 1$
$\lambda_1 \cdot P_2 \cdot P_5 \cdot P_7 \cdot P_9 \cdot P_{11}$	$V_1 := 2; V_2 := 2; V_3 := 2; V_6 := 5$
$\lambda_1 \cdot P_2 \cdot P_5 \cdot P_7 \cdot P_{10} \cdot P_{12}$	$V_1 := 2; V_2 := 2; V_3 := 2; V_6 := 6$
$\lambda_1 \cdot P_2 \cdot P_5 \cdot P_7 \cdot P_9 \cdot P_{12}$	$V_1 := 2; V_2 := 2; V_3 := 2; V_6 := 7$
$\lambda_1 \cdot P_2 \cdot P_5 \cdot P_7 \cdot P_{10} \cdot P_{11}$	$V_1 := 2; V_2 := 2; V_3 := 2; V_6 := 8$
$\lambda_1 \cdot P_2 \cdot P_6 \cdot P_8 \cdot P_9 \cdot P_{11}$	$V_1 := 2; V_2 := 3; V_3 := 3; V_6 := 5$
$\lambda_1 \cdot P_2 \cdot P_6 \cdot P_8 \cdot P_{10} \cdot P_{12}$	$V_1 := 2; V_2 := 3; V_3 := 3; V_6 := 6$
$\lambda_1 \cdot P_2 \cdot P_6 \cdot P_8 \cdot P_9 \cdot P_{12}$	$V_1 := 2; V_2 := 3; V_3 := 3; V_6 := 7$
$\lambda_1 \cdot P_2 \cdot P_6 \cdot P_8 \cdot P_{10} \cdot P_{11}$	$V_1 := 2; V_2 := 3; V_3 := 3; V_6 := 8$
$\lambda_1 \cdot P_2 \cdot P_5 \cdot P_8 \cdot P_9 \cdot P_{11}$	$V_1 := 2; V_2 := 2; V_3 := 3; V_6 := 5$
$\lambda_1 \cdot P_2 \cdot P_5 \cdot P_8 \cdot P_{10} \cdot P_{12}$	$V_1 := 2; V_2 := 2; V_3 := 3; V_6 := 6$
$\lambda_1 \cdot P_2 \cdot P_5 \cdot P_8 \cdot P_9 \cdot P_{12}$	$V_1 := 2; V_2 := 2; V_3 := 3; V_6 := 7$
$\lambda_1 \cdot P_2 \cdot P_5 \cdot P_8 \cdot P_{10} \cdot P_{11}$	$V_1 := 2; V_2 := 2; V_3 := 3; V_6 := 8$
$\lambda_1 \; P_2 \cdot P_6 \cdot P_7 \cdot P_9 \cdot P_{11}$	$V_1 := 2; V_2 := 3; V_3 := 2; V_6 := 5$

Continuation of Table 1

1	2
$\lambda_1 \cdot P_2 \cdot P_6 \cdot P_7 \cdot P_{10} \cdot P_{12}$	$V_1 := 2; V_2 := 3; V_3 := 2; V_6 := 6$
$\lambda_1 \cdot P_2 \cdot P_6 \cdot P_7 \cdot P_9 \cdot P_{12}$	$V_1 := 2; V_2 := 3; V_3 := 2; V_6 := 7$
$\lambda_1 \cdot P_2 \cdot P_6 \cdot P_7 \cdot P_{10} \cdot P_{11}$	$V_1 := 2; V_2 := 3; V_3 := 2; V_6 := 8$
$\lambda_1 \cdot P_3 \cdot P_7 \cdot P_{11}$	$V_1 := 2; V_2 := 1; V_3 := 2; V_6 := 3$
$\lambda_1 \cdot P_3 \cdot P_7 \cdot P_{12}$	$V_1 := 2; V_2 := 1; V_3 := 2; V_6 := 4$
$\lambda_1 \cdot P_3 \cdot P_8 \cdot P_{11}$	$V_1 := 2; V_2 := 1; V_3 := 3; V_6 := 3$
$\lambda_1 \cdot P_3 \cdot P_8 \cdot P_{12}$	$V_1 := 2; V_2 := 1; V_3 := 3; V_6 := 4$
$\lambda_1 \; P_4 \cdot P_5 \cdot P_9 \cdot$	$V_1 := 2; V_2 := 2; V_3 := 1; V_6 := 1$
$\lambda_1 \cdot P_4 \cdot P_5 \cdot P_{10}$	$V_1 := 2; V_2 := 2; V_3 := 1; V_6 := 2$
$\lambda_1 \cdot P_4 \cdot P_6 \cdot P_9 \; 9$	$V_1 := 2; V_2 := 3; V_3 := 1; V_6 := 1$
$\lambda_1 \cdot P_4 \cdot P_6 \cdot P_{10}$	$V_1 := 2; V_2 := 3; V_3 := 1; V_6 := 2$

Table 2

Tree of modification rules state vector component for BE2

BE2: End of MO location beyond far control zone (MO appearance in sensitivity zone of SS3 and SS4) (CBE7, CBE8, CBE9, CBE10)	
Description of situation when BE2 takes place: V_1=2	
FCBEI	MRSVC
$\lambda_2 \cdot P_{13}$	$V_1 := 3; V_4 := 1; V_5 := 1$
$\lambda_2 \cdot P_{14} \cdot P_{17} \cdot P_{19} \cdot P_{21} \cdot P_{23}$	$V_1 := 3; V_4 := 2; V_5 := 2; V_7 := 5$
$\lambda_2 \cdot P_{14} \cdot P_{17} \cdot P_{19} \cdot P_{22} \cdot P_{24}$	$V_1 := 3; V_4 := 2; V_5 := 2; V_7 := 6$
$\lambda_2 \cdot P_{14} \cdot P_{17} \cdot P_{19} \cdot P_{21} \cdot P_{24}$	$V_1 := 3; V_4 := 2; V_5 := 2; V_7 := 7$
$\lambda_2 \cdot P_{14} \cdot P_{17} \cdot P_{19} \cdot P_{22} \cdot P_{23}$	$V_1 := 3; V_4 := 2; V_5 := 2; V_7 := 8$
$\lambda_2 \cdot P_{14} \cdot P_{18} \cdot P_{20} \cdot P_{21} \cdot P_{23}$	$V_1 := 3; V_4 := 3; V_5 := 3; V_7 := 5$
$\lambda_2 \cdot P_{14} \cdot P_{18} \cdot P_{20} \cdot P_{22} \cdot P_{24}$	$V_1 := 3; V_4 := 3; V_5 := 3; V_7 := 6$
$\lambda_2 \cdot P_{14} \cdot P_{18} \cdot P_{20} \cdot P_{21} \cdot P_{24}$	$V_1 := 3; V_4 := 3; V_5 := 3; V_7 := 7$
$\lambda_2 \cdot P_{14} \cdot P_{18} \cdot P_{20} \cdot P_{22} \cdot P_{23}$	$V_1 := 3; V_4 := 3; V_5 := 3; V_7 := 8$
$\lambda_2 \cdot P_{14} \cdot P_{17} \cdot P_{20} \cdot P_{21} \cdot P_{23}$	$V_1 := 3; V_4 := 2; V_5 := 3; V_7 := 5$
$\lambda_2 \cdot P_{14} \cdot P_{17} \cdot P_{20} \cdot P_{22} \cdot P_{24}$	$V_1 := 3; V_4 := 2; V_5 := 3; V_7 := 6$
$\lambda_2 \cdot P_{14} \cdot P_{17} \cdot P_{20} \cdot P_{21} \cdot P_{24}$	$V_1 := 3; V_4 := 2; V_5 := 3; V_7 := 7$
$\lambda_2 \cdot P_{14} \cdot P_{17} \cdot P_{20} \cdot P_{22} \cdot P_{23}$	$V_1 := 3; V_4 := 2; V_5 := 3; V_7 := 8$
$\lambda_2 \cdot P_{14} \cdot P_{18} \cdot P_{19} \cdot P_{21} \cdot P_{23}$	$V_1 := 3; V_4 := 3; V_5 := 2; V_7 := 5$
$\lambda_2 \cdot P_{14} \cdot P_{18} \cdot P_{19} \cdot P_{22} \cdot P_{24}$	$V_1 := 3; V_4 := 3; V_5 := 2; V_7 := 6$
$\lambda_2 \cdot P_{14} \cdot P_{18} \cdot P_{19} \cdot P_{21} \cdot P_{24}$	$V_1 := 3; V_4 := 3; V_5 := 2; V_7 := 7$
$\lambda_2 \cdot P_{14} \cdot P_{18} \cdot P_{19} \cdot P_{22} \cdot P_{23}$	$V_1 := 3; V_4 := 3; V_5 := 2; V_7 := 8$
$\lambda_2 \cdot P_{15} \cdot P_{19} \cdot P_{23}$	$V_1 := 3; V_4 := 1; V_5 := 2; V_7 := 3$
$\lambda_2 \cdot P_{15} \cdot P_{19} \cdot P_{24}$	$V_1 := 3; V_4 := 1; V_5 := 2; V_7 := 4$
$\lambda_2 \cdot P_{15} \cdot P_{20} \cdot P_{23}$	$V_1 := 3; V_4 := 1; V_5 := 3; V_7 := 3$
$\lambda_2 \cdot P_{15} \cdot P_{20} \cdot P_{24}$	$V_1 := 3; V_4 := 1; V_5 := 3; V_7 := 4$
$\lambda_2 \cdot P_{16} \cdot P_{17} \cdot P_{21}$	$V_1 := 3; V_4 := 2; V_5 := 1; V_7 := 1$
$\lambda_2 \cdot P_{16} \cdot P_{17} \cdot P_{22}$	$V_1 := 3; V_4 := 2; V_5 := 1; V_7 := 2$
$\lambda_2 \cdot P_{16} \cdot P_{18} \cdot P_{21}$	$V_1 := 3; V_4 := 3; V_5 := 1; V_7 := 1$
$\lambda_2 \cdot P_{16} \cdot P_{18} \cdot P_{22}$	$V_1 := 3; V_4 := 2; V_5 := 1; V_7 := 2$

Developing of SAM finishes with its verification. The essence of verification method is in finding discrepancies in comparing test model of the object under research in the form of graph of states and transitions with the graph of states and transitions which forms software module ASNA-1 on the basis of SAM, and elimination of errors that are the cause of discrepancies. Development of test model is carried out by method of single-step analysis of states for actual BEs [12] and it is given in Table 3.

Table 3

Test model of reaction of guard signaling complex on MO appearance

№	State and BE that are examined	State vector							№ of state	Transition from state to state	Intensity of BE
		V_1	V_2	V_3	V_4	V_5	V_6	V_7			
1	IS	1	0	0	0	0	0	0	1	-	-
2	1BE1	2	1	1	0	0	0	0	2	1→2	λ_1
3	2BE2	3	1	1	1	1	0	0	3	2→3	λ_2
4	2BE2	3	1	1	2	2	0	5	4	2→4	λ_2
5	2BE2	3	1	1	2	2	0	6	5	2→5	λ_2
6	2BE2	3	1	1	2	2	0	7	6	2→6	λ_2
7	2BE2	3	1	1	2	2	0	8	7	2→7	λ_2
8	2BE2	3	1	1	3	3	0	5	8	2→8	λ_2
9	2BE2	3	1	1	3	3	0	6	9	2→9	λ_2
10	2BE2	3	1	1	3	3	0	7	10	2→10	λ_2
11	2BE2	3	1	1	3	3	0	8	11	2→11	λ_2
12	2BE2	3	1	1	2	3	0	5	12	2→12	λ_2
13	2BE2	3	1	1	2	3	0	6	13	2→13	λ_2
14	2BE2	3	1	1	2	3	0	7	14	2→14	λ_2
15	2BE2	3	1	1	2	3	0	8	15	2→15	λ_2
16	2BE2	3	1	1	3	2	0	5	16	2→16	λ_2
17	2BE2	3	1	1	3	2	0	6	17	2→17	λ_2
18	2BE2	3	1	1	3	2	0	7	18	2→18	λ_2
19	2BE2	3	1	1	3	2	0	8	19	2→19	λ_2
20	2BE2	3	1	1	1	2	0	3	20	2→20	λ_2
21	2BE2	3	1	1	1	2	0	4	21	2→21	λ_2
22	2BE2	3	1	1	1	3	0	3	22	2→22	λ_2
23	2BE2	3	1	1	1	3	0	4	23	2→23	λ_2
24	2BE2	3	1	1	2	1	0	1	24	2→24	λ_2
25	2BE2	3	1	1	2	1	0	2	25	2→25	λ_2
26	2BE2	3	1	1	3	1	0	1	26	2→26	λ_2
27	2BE2	3	1	1	3	1	0	2	27	2→27	λ_2
28	1BE1	2	2	2	0	0	5	0	28	1→28	λ_1
29	28BE2	3	2	2	1	1	5	0	29	28→29	λ_2
30	28BE2	3	2	2	2	2	5	5	20	28→30	λ_2
...											
649	626BE2	3	3	1	2	1	2	2	649	626→ →649	λ_2
650	626BE2	3	3	1	3	1	2	1	650	626→ →650	λ_2
651	626BE2	3	3	1	3	1	2	2	651	626→ →651	λ_2

Generated graph has 651 states and 676 transitions. On the base of this graph a mathematical model of GSC reaction on the MO appearance has been made, with pairwise placement of SS_S in far and close control zones in the form of system of differential equations of Kolmogorov – Chapman.

$$\frac{dQ_1(t)}{dt} = -\lambda_1 Q_1(t)(P_1 + (P_2(P_5 + P_6)(P_9 + P_{10}) +$$

$$+P_3)(P_7 + P_8)(P_{11} + P_{12}) + P_4(P_5 + P_6)(P_9 + P_{10})),$$

$$\frac{dQ_2(t)}{dt} = \lambda_1 Q_1(t) P_1 - \lambda_2 Q_2(t)(P_{13} +$$

$$+(P_{14}(P_{21} + P_{22})(P_{17} + P_{18}) + P_{15})(P_{23} + P_{24})(P_{19} + P_{20}) +$$

$$+P_{16}(P_{21} + P_{22})(P_{17} + P_{18})),$$

$$\frac{dQ_3(t)}{dt} = \lambda_2 \cdot Q_2(t) \cdot P_{13},$$

....

$$\frac{dQ_{649}(t)}{dt} = \lambda_2 \cdot Q_{626}(t) \cdot P_{16} \cdot P_{17} \cdot P_{22},$$

$$\frac{dQ_{650}(t)}{dt} = \lambda_2 \cdot Q_{626}(t) \cdot P_{16} \cdot P_{18} \cdot P_{21},$$

$$\frac{dQ_{651}(t)}{dt} = \lambda_2 \cdot Q_{626}(t) \cdot P_{16} \cdot P_{18} \cdot P_{22},$$

where $dQ_1(t)...dQ_{651}(t)$ – probabilities of location of the object under research in states from one to six hundred fifty one.

4. Results of comparative analysis of GSC effectiveness

Suggested mathematical model of GSC reaction on MO appearance with pairwise SS_S placement in far and close control zones, and also model of GSC reaction given in [1, 2] have the necessary level of adequacy and allow receiving reliable results concerning effectiveness of its work.

Effectiveness of GSC work is studied with different requirements to the method of MO classification and to the system of radio signal transmitting under the condition of given SS sensitivity with a glance of ground, relief of the area, distance of MO from SS, MO weight and speed. GSC effectiveness is evaluated by probability of detection and correct MO classification due to the signal of even one SS ($P_{S,f}$).

In order to conduct researches the authors set actual for practical realization ranges of changes of probability values for correct MO classification ($P_{c,c}$) and probability of correct radio signal receiving RDI ($P_{c,r}$) from 0.6 to 0.99.Probability values of SS reaction on MO appearance are given with a glance of the fact that SS_S are installed on soft ground.

Fig. 2 – 5 show dependences of GSC effectiveness on probability of correct MO classification and on probability of correct radio signal receiving for four layouts of SS_S placement on possible routes of moving object movement. It is accepted in the researches that the value of probability of successful fulfilment of the GSC task has to be not less than 0.95.

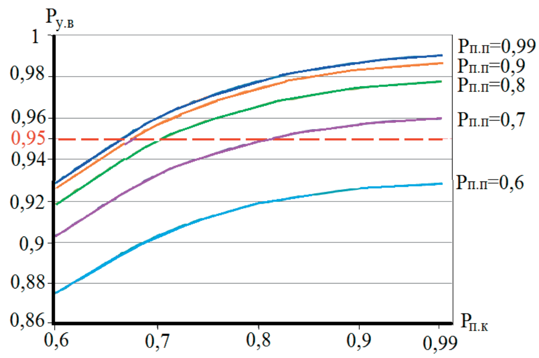

Fig. 2. Dependence of GSC effectiveness ($P_{S,f}$) on $P_{c,c}$ and $P_{c,r}$ during placement of four SS_S in pairs in far and close control zones

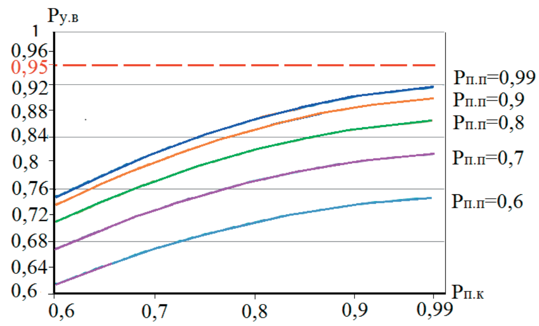

Fig. 3. Dependence of GSC effectiveness ($P_{S,f}$) on $P_{c,c}$ and $P_{c,r}$ during placement of two SS_S on the border in far and close control zones

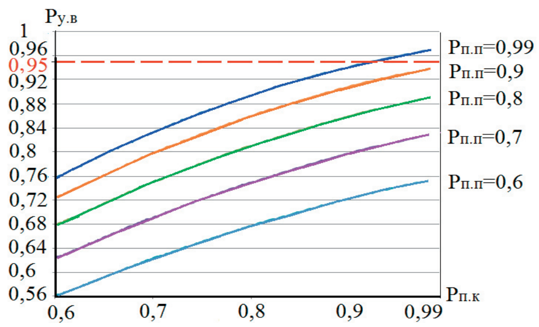

Fig. 4. Dependence of GSC effectiveness ($P_{S,f}$) on $P_{c,c}$ and $P_{c,r}$ during placement of two SS_S serially in far and close control zones

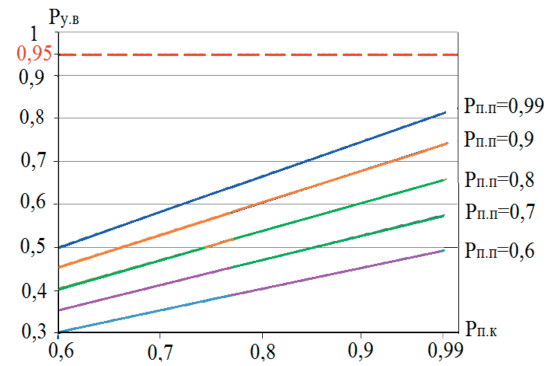

Fig. 5. Dependence of GSC effectiveness ($P_{S,f}$) on $P_{c,c}$ and $P_{c,r}$ during placement of one SS in far or close control zones

5. Conclusion

The received results showed that in order to ensure probability of successful fulfilment of seismic sensor task on the soft ground not less than 0.95, it is necessary to place four seismic sensors pairwise in far and close control zones. And requirements to the method of seismic sensor classification and to the system of radio signal transmitting can be not high. To ensure high requirements it is possible to place two SS_s – one in far control zone and one in close control zone. Suggested models are assumed as a basis of the methods which gives possibility to determine parameters of seismic sensor classification device and system of transmitting radio signals with given seismic sensor sensitivity under the worst conditions of their use. And vice versa, it is possible to determine seismic sensor sensitivity with given parameters of classification device and system of transmitting radio signals.

Mentioned results show what requirements it is necessary to lay down to the classification method and the way of signal transmitting in order to keep given effectiveness of guard signaling complex ($P_{S,f} = 0.95$), if necessary, to reduce number of seismic sensors on probable route of moving object movement from four to two.

In further researches concerning creating perspective guard signaling complex, one should pay attention to the improvement of the method of moving object classification on the basis of signals from seismic sensors.

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СИСТЕМА ОБРАБОТКИ СИГНАЛОВ ЦИФРОВЫХ УСТРОЙСТВ НА ОСНОВЕ К-ЗНАЧНОГО ДИФФЕРЕНЦИАЛЬНОГО ИСЧИСЛЕНИЯ

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Представлено систему моделювання на основі К-значного диференційного числення, яка дозволяє отримати більш якісне і точне моделювання в порівнянні з двійковим моделюванням за рахунок обліку при моделюванні крутизни фронтів, К-значного квантування рівня сигналів по амплітуді та обліку електромагнітної сумісності. Моделювання в системі виконується за рахунок спільного розв’язання звичайних К-значних диференціальних рівнянь і К-значних диференціальних рівнянь із запізненням

Ключові слова: система моделювання, К-значне диференційне числення, електромагнітна сумісність, квантування сигналів

Представлена система моделирования на основе К-значного дифференциального исчисления, которая позволяет получить более качественное и точное моделирование по сравнению с двоичным моделированием, за счет учета при моделировании крутизны фронтов, К-значного квантования уровня сигналов по амплитуде и учета электромагнитной совместимости. Моделирование в системе выполняется за счет совместного решения обыкновенных К-значных дифференциальных уравнений и К-значных дифференциальных уравнений с запаздыванием

Ключевые слова: система моделирования, К-значное дифференциальное исчисление, электромагнитная совместимость, квантование сигналов

1. Введение

Сложность современных элементов и устройств вычислительной техники требует для их разработки создания новых методов и средств, позволяющих учитывать при их проектировании особенности применяемых технологий. Одним из возможных путей решения этой задачи является разработка новых не-