Decision Making in Geotechnical Monitoring Systems

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Abstract. The article considers an algorithm for estimating the moments of correction of the list of controlled and measured parameters, selecting control points and correcting an individual model of a geotechnical object. As a criterion for correcting the list of parameters, it is proposed to use the moments when the values of the controlled parameters approach the critical zone. The choice of parameters for measurement is carried out on the basis of optimization of the ratio of the cost of monitoring to possible damage. The definition of key control zones is carried out according to the criterion of sensitivity of monitoring zones to changes in external parameters. The practical verification was carried out on the data of geotechnical monitoring of a three-storey building in which destructive processes were recorded.

1. Introduction
Monitoring of the geotechnical system must be carried out throughout the entire life cycle of the geotechnical system [1]: from the design stage to the stage of dismantling and reclamation. The requirements of the continuous monitoring of the geotechnical system are associated with the possible development of destructive processes and the occurrence of accidents and catastrophes of a technogenic nature. The number of such accidents and catastrophes increases every year [2-4]. Some negative factors in the design are taken into account using probabilistic parameters or are not attributed to significant parameters. However, insignificant factors can become significant with the development of the geotechnical system and an increase in the anthropogenic load on the geological environment [5-7]. At the same time, it is not possible to provide complete a priori information about the state of all system components at the design or operation stage of a geotechnical system or its individual sections using monitoring systems, which is due to technical and economic limitations [8]. Thus, the consequences of making technical and managerial decisions in some cases can be negative and are of a probabilistic nature. To increase the probability of making the right decisions, diagnostic matrices are currently being formed, which have already been tested in practice, probabilistic models of risk compliance with destructive processes and types of deformations are being formed [9-11]. A priori uncertainty is partially eliminated by methods based on the "black box" model using intelligent algorithms [12-15].

The purpose of this work is to increase the efficiency of the decision-making unit in automated geotechnical monitoring systems by increasing its adaptability to hidden destructive processes when organizing monitoring under technical and economic constraints.

2. Methods and approaches
Geotechnical monitoring systems include three main subsystems: the collection subsystem, the analysis subsystem and the decision-making subsystem. Sensors of the collection subsystem are placed at control points, which are selected based on model data and a priori information based on design and regulatory...
documentation. With a limited set of measurement points and measured parameters, the operation of the collection subsystem in a stationary mode does not always allow registering the initial stages of the development of destructive processes. This happens in the case of the development of destructive processes between control points. Moreover, the registration of destructive processes occurs already at a late stage.

In turn, the analysis subsystem forms its estimates based on the available models. Correction of models is carried out with a full understanding of the reasons for its mismatch, which is not always possible in practice. To partially solve the problems described above, it is proposed to make the following changes to the functioning of the geotechnical monitoring system. The range of values of the controlled parameters is divided into areas: permissible, critical, beyond the design. This separation is carried out on the basis of model data and regulatory documentation. The permissible area corresponds to the values of the parameters of the functioning of the elements of the geotechnical system within the calculated (design) values, minus the critical zone. The upper limit of the critical zone is determined by the values of the bifurcation points, in case it is not possible to estimate the bifurcation points, its upper limit is determined by the maximum permissible values from the project documentation and models. The lower limit of the critical zone is determined based on the required permitted range – it is estimated depending on the hazard category of the geotechnical object and possible risks.

To assess the transition of a geotechnical system to another state, it is proposed to use a recurrent network in order to assess the general state of the geotechnical system based on the state of parameters at key control points [14, 15]. The training of the neural network is carried out on the basis of existing models with a search for the values of the maximum number of parameters, while training samples are formed that correspond to acceptable, critical and project situations.

The number and locations of control points are determined on the basis of a modular model of the geotechnical system, which shows the interaction of parameters between zones [16]. The most sensitive zone is considered to be the zone in which, with minimal input influences, the maximum reaction occurs – the deviation of the controlled parameters:

$$\text{max} \left( \frac{1}{N_i} \sum_i dP_i / (\Delta_i \cdot dt) \right),$$

(1)

where $i$ is the analyzed control zone; $N$ is the number of controlled parameters in the control zone; $P_i$ is the $i$-th controlled parameter; $\Delta_i$ is the permissible range of the parameter $P_i$ in the $i$-th control zone.

The bifurcation zone is estimated by the distance from the point that describes the current state of the geotechnical system to the boundaries of classes that characterize other states of the geotechnical system

$$\text{min}(L_i / d),$$

(2)

where $L_i$ is the distance from the current position of the geotechnical system in the space of controlled parameters to the boundary of the $i$-ko class; $d$ is the fluctuations of the point describing the current position of the controlled system (standard deviation).

The collection and analysis subsystems are managed on the basis of the following points:

- The composition of the controlled parameters is changed (revised) when the boundary between the permissible and critical zones of the controlled parameter is reached in one of the control zones. The choice of controlled parameters is based on a modular model (the approach is described in [16]). The selection of the measured parameters is carried out from the composition of the controlled parameters based on the author's algorithm and the optimization criterion for the cost/damage indicator [8].
- The control zone is selected based on the expression (1).
- The need to revise the model is realized when the state of the geotechnical system reaches a critical level – the point in the multiparametric space approaches the edge of the permissible boundary (according to expression (2)).
3. Practical verification
The practical verification of the proposed algorithm was carried out on the data of geotechnical monitoring. The object of monitoring was a three-story building at the address Murom, Radiozavodskoe highway 23. During the monitoring, the development of destructive processes was recorded (figure 1) and the subsequent violation of the stability of individual structural elements with the formation of cracks in the external capital and internal wall (figure 2).

![Figure 1. The place of development of destructive processes.](image)

![Figure 2. Crack in the main wall.](image)

The resulting change in the risk assessment of the stability violation of the studied section of the object (Figure 3) corresponds to a change in the natural frequency of vibrations of the studied section (Figure 4).
The development of a decision on the correction of the list of controlled parameters and the inclusion of temperature and humidity in it corresponds to the model data on changes in soil stability with increasing humidity (Figure 5) – which, according to the results of geotechnical monitoring, was the cause of the stability violation.
Figure 5. The model of the development of destructive processes.

4. Conclusion
The proposed criteria for the need to revise the controlled parameters, control points and models in the experiment under consideration confirmed the probability of a correct solution. The simulation data are consistent with the results of geotechnical monitoring. To assess the probabilities of correct decision-making, it is necessary to test the algorithm on a larger number of geotechnical monitoring systems. However, this will require retraining the neural network model and rebuilding the modular model to adapt to the individual characteristics of the geotechnical object.

5. References
[1] Scheider-Gloetzl J, Gloetzl R, Kребber K, Liehr S and Wendt M 2010 European Workshop Structural Health Monitoring (Sorrento: Italy/Glotzl) pp 1301-12
[2] Yu H, Wang Y M, Qiu P Y and Chen J C 2018 2nd Int. Conf. on Functional Materials and Chemical Engin. vol 272 (Abu Dhabi: UAE/ICFMCE) pp 1-10
[3] Yang X, Gao Y, Wang H and Zhang J 2014 Sixth Int. Conf. on Measuring Techno. and Mechatronics Automation (URUUS:USA) pp 480-3
[4] AlHamaydeh M and Elayyan L 2017 7th Int. Conf. on Modeling, Simulation, and Applied Optimization (Sharjah:UAE/IEEE) pp 1-4
[5] Krishbaum D, Watson C S, Rounce D R, Shugar D H, Kargel J S, Haritashya U K, Amatya P, Shean D, Anderson E R and Jo M 2019 Frontiers in Earth science 7 197
[6] Gigin S, Necci A and Krausmann E 2019 Int. J. of Disaster risk reduction 35 101072
[7] Strzalkowski P 2019 Environmental Earth Sci. 78 9
[8] Dorofeev N V, Grecheneva A V, Romanov R V and Pankina E S 2020 IOP Conf. Ser.: Mater. Sci. and Eng. 873(1) 1-8
[9] Potapov A D and Manko A V 2012 Vestnik MGSU 11 227-35
[10] Sokolov V, Musorina T, Starshinova E and Popovych I 2016 MATEC Web of Conferences vol 73, ed T Maltseva (Tyumen: Russia) 04016
[11] Melchakov A P adn Cheboksar D V 2018 Prospects of science 9 133-6
[12] Lydia M, Kumar S S, Selvakumar A I and Kumar G E P 2015 Renewable energy 83 425-34
[13] Tabarsa A, Latifi N, Ossouli A and Bagheri Y 2021 Frontier of Stru. and Civil Engin. 15 520-36
[14] Wang Q and Huang H 2017 36th Chinese Control Conf. (DLTU:China/IEEE) pp 4135-9
[15] Zhao W, Li X, Wang N and Xu T 2019 IEEE International Conference on Unmanned Systems (Paris:France/IEEE) pp 773-7
[16] Dorofeev N V, Romanov R V, Grecheneva A V and Pankina E S 2020 IOP Conf. Series: Earth and Envir. Sci. 548(5) 1-5

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