UDC 624.137.2

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THE EARLY WARNING SYSTEMS ABOUT LANDSLIDE HAZARDS IN UKRAINE

Abstract. *Early warning systems are an effective tool for preventing and mitigating the risks associated with the occurrences of various types of threats (including landslides). The paper presents and describes the concept and practical implementation of the new integrated methodology for early warning systems based on the integration of modern monitoring technologies and comprehensive numerical modeling of an object under study. Designing, testing and operation of monitoring systems of complex and unique construction objects have a lot of difficulties, need system knowledge in several spheres of science and engineering: construction, informational technologies, measuring instruments, systems and algorithms of data processing, programming etc. This information is known only to narrow range of highly qualified specialists that directly participated in designing and installing of the particular monitoring system at the particular construction object. The basic concept of Early Warning System installed on landslides is that the elements at risk, especially people being close from the dangerous area, must have sufficient time to evacuate, if an imminent collapse is expected. Therefore, an effective Early Warning System shall include such four main sets of actions: monitoring of the activity of the observed object, i.e. the data collection and transmission, as well as the equipment maintenance; the analysis and modeling of the observed and studied object; warning, i.e. the dissemination of simple and clear information about the observed object; the effective response of risk exposed elements; full understanding of risks. The examples of the practical application of the proposed integrated methodology to various construction projects and natural and technological systems are given, including 1) Central Livadia Landslide System and Livadia Palace; 2) a system for landslide hazard areas monitoring in the Kharkiv region; and 3) landslides Early Warning System using unmanned aerial vehicles as a specialized monitoring system for shearing deformations.*
Keywords: *methodology; hazard early warning; monitoring and numerical modeling*

DOI: 10.32347/2411-4049.2021.1.83-94

Introduction

Historical beginning of monitoring was observation of levels of oxide of hydrocarbon in air at coal mines in England and Belgium more than 100 years ago [1]. Canaries, guinea pigs and cockroaches were used as sensors at that time. Designing, testing and operation of ordinary monitoring systems have a lot in common in different countries and are developed traditional technologies [2]. At the same time designing, testing and operation of monitoring systems of complex and unique construction objects have a lot of difficulties, researches and substantiations, need system knowledge in several spheres of science and engineering: construction, informational technologies, measuring instruments, systems and algorithms of data processing, programming etc [3–6]. This information is known only to narrow range of highly qualified specialists that directly participated in designing and installing of the particular monitoring system at the particular construction object [7–9].

The early stage of the landslide hazards automated study has begun with a variety of monitoring systems, the main role of which was to collect information about an object or phenomenon under study [10–11]. The study of landslide hazards requires the responses to two fundamental questions [12–15]:

1. "Where and when can landslides occur?" and

2. "How to avoid them or mitigate their consequences?"

The purpose of monitoring is to determine the points of time, at which the deviations from the normal operation of the object under study occur. *The main task* to be solved in the process of monitoring is the detection and assessment of the recorded field deviation from the stationary state. To identify the object state by means of analysis, the most informative indicative parameters, the combination of which represents the state of the object under study, should be selected. In the process of monitoring, the actual values of indicative parameters shall be recorded [16, 17].

As defined by the UN International Strategy for Environmental Disaster Reduction (UN International Strategy for Disaster Reduction, UNISDR 2009), the Early Warning System (EWS) is "*the set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss*" [18].

This general definition can be applicable to any danger and does not contain a direct reference to landslides. Regardless of the definition and the hazard considered, EWS is used to reduce the risk by affecting the impact on exposed elements. The basic concept of EWS installed on landslides is that the elements at risk, especially people being away from the dangerous area, must have sufficient time to evacuate, if an imminent collapse is expected.

Therefore, an effective EWS shall include such four main sets of actions [19]:

• Monitoring of the activity of the observed object, i.e. the data collection and transmission, as well as the equipment maintenance;

• The analysis and modeling of the observed and studied object;

• Warning, i.e. the dissemination of simple and clear information about the observed object;

• The effective response of risk exposed elements; full understanding of risks.

The key to the successful application of landslides EWS is the system ability to identify and measure in real time a limited number of important indicators called precursors that precede landslide catastrophic movements including disturbances and collapses. The recent advances in the development of control and measuring equipment in conjunction with GPS and photogrammetric techniques have increased the potential for obtaining the highly reliable measurements of various parameters, which then can be used to detect landslide activity preceding the entire slope breakage [20–28]. *It is quite obvious that whenever the mechanics and instability mechanism of a particular slope are ignored, it may be difficult or simply impossible to rely solely on the analysis based on the measurements of surface displacements and velocities. Therefore, it is necessary to describe the landslide forerunners for the purposes of early warning about soil movements* [29–31].

1. System of monitoring the Central Livadia Landslide system and Livadia palace.

As the first illustration of the LH EWS NIM practical embodiment the project «System of monitoring the Central Livadia Landslide system and Livadia palace» [32, 33] implemented during 2002–2014 (*project chairmans O. Trofymchuk and I. Kaliukh*) can be taken. In this project unit 2, unit 3 and partially unit 4 of the four units of the LH EWS were implemented. To study the state of the geological environment of the the Central Livadia Landslide system and Livadia palace the monitoring system was developed and technically implemented on the computer (ZSUV software is shown in fig. 1).

Fig. 1 – The ZSUV software for the Central Livadia landslide system and Livadia palace monitoring (*first version, 2002*)

Heliogenic parameters included solar activity, changes in temperature and humidity regimes, the nature and intensity of precipitation, wind activity etc. The data were manually loaded into the computer. Lithogenic parameters were presented by a set of conditions and factors characterizing the mechanism and dynamics of changes in the equilibrium state of the the Central Livadia Landslide system slopes. The system performed the following actions:

1. Control of the the Central Livadia Landslide system and Livadia palace reference points displacements by means of landslide surface visual observations and subsequent manual loading of information into the PC (fig. 2).

2. The continuous real-time monitoring of the evolution of deviation angle changes for selected areas and zones within the landslide massif with the use of high precision electric inclinometers, filtering of electrical signals, converting of analog signals into a digital code by means of the analog-to-digital converter and data real-time downloading into the PC (fig. 3).

The processing of the measurement results showed the following [6]:

1. The southeastern wing of the Livadia palace performs continuous waves relative to a certain intermediate position. These vibrations are of a noticeable periodic nature with a period being defined as twenty-four hours. The amplitude of daily vibrations varies within the range of approximately 1.5 angular minutes, that is, about 45 angular seconds to every side away from the intermediate position. The vibrations are directed relative to the transverse building axis.

2. Sometimes (for example, on February 13–14, February 26–27 and March 22–23, 2002), the Livadia Palace tilt angle increase was recorded. In those cases, the amplitude increased to 6 angular minutes. The calculation results showed that the usual daily vibrations were 1.9 mm to each side from the intermediate position, but on the mentioned days the vibrations were about 4.2 mm to each side from the intermediate position.

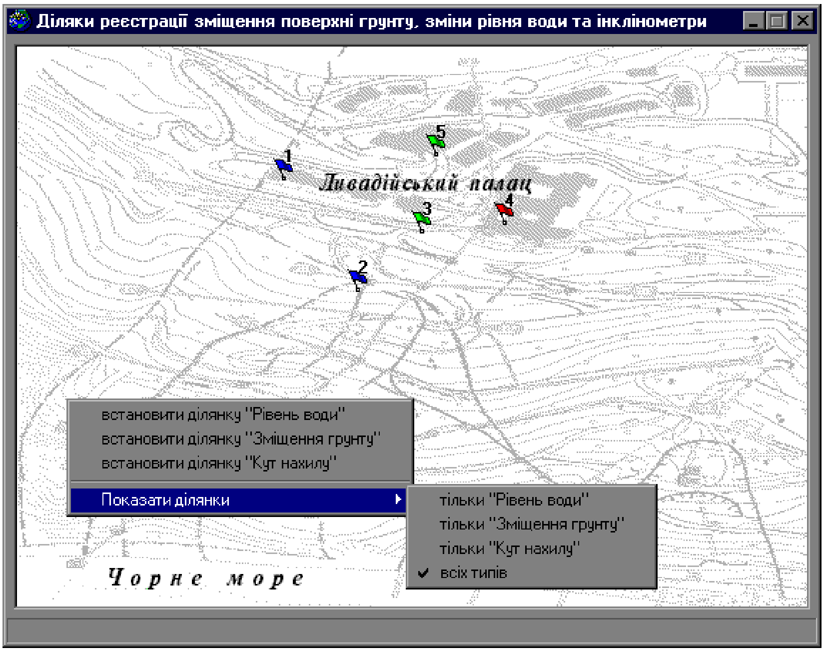

Fig. 2 – Central Livadia Landslide system and Livadia palace GIS unit

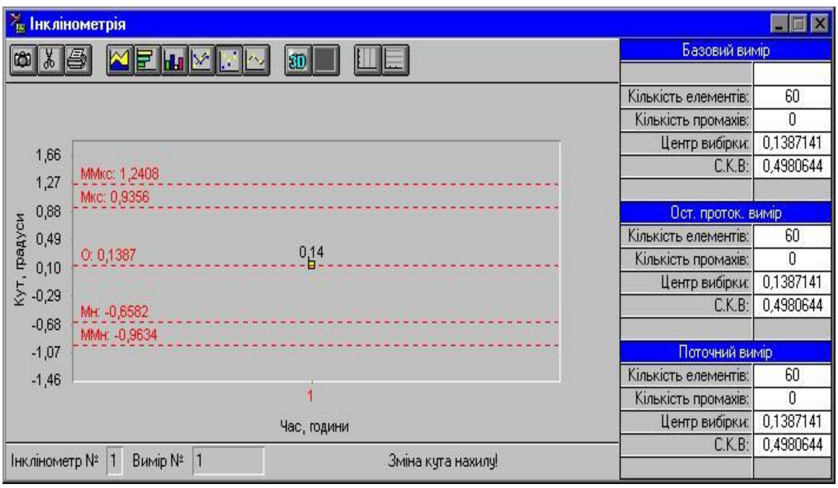

Fig. 3 – «Inclinometer» Unit of the Central Livadia Landslide system and Livadia palace

3. The exact correlation of those factors with the Livadia Palace civil structures dynamics was not proved because of the frequent forced breaks in the monitoring system operation. Such breaks were caused by the necessity to fulfill the mandatory requirements of the Security Service of Ukraine during the various official events of the All-Ukrainian and local (Yalta and Livadia) levels in the Livadia Palace and preliminary preparations for them. Since January 2014, the monitoring of the the Central Livadia Landslide system and Livadia palace has been completely ceased because of the occupation Crimea by Russia.

2. The project “System of GIS-monitoring of the landslide hazard slopes in Kharkivska oblast by means of ERS”.

It implemented during 2008–2011 (*project chairman O. Trofymchuk*) can be taken as the second illustration of the LH EWS NIM practical embodiment. In the project unit 1, partially unit 3 and partially unit 4 of the four units of the LH EWS NIM were implemented.

The proprietary database and GIS (fig. 4) were taken as the basis for the proposed structure of the landslide hazard slopes information system. The developed database had an information and reference character and contained brief information about fifty two certificates of the Kharkiv region landslide areas and the data on the total precipitation during twenty years from 1983 to 2002 at the Kharkiv region meteorological stations. The database information could be used for the rapid assessment of the landslides formation risk. GIS contained the multilayer information on relief, gradients of slopes, hydrographic network, roads, landslide areas etc.

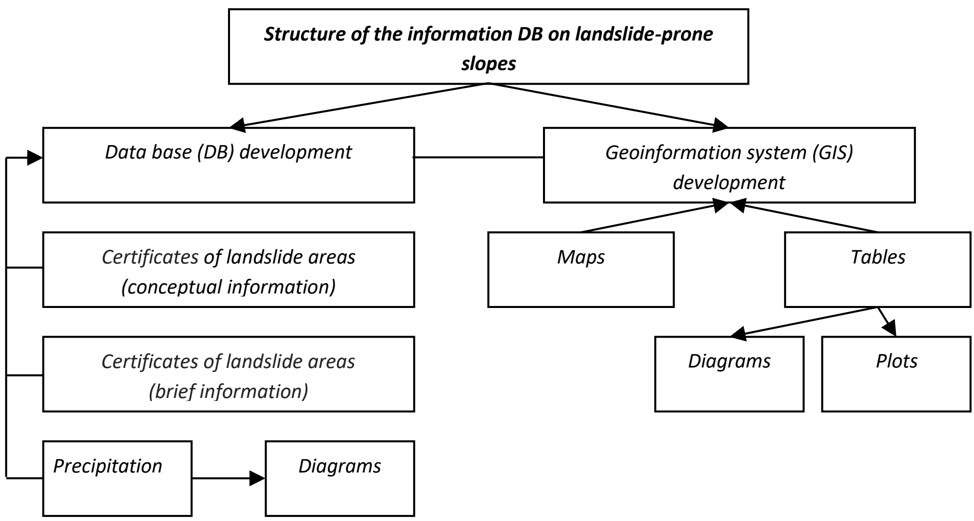

Fig. 4 – Structure of an information database on landslide hazard slopes

Fig. 5 shows that the shorter distance between the road and landslide areas, the bigger number of landslides. Although the Kharkiv region territory is relatively small in size, its main part is struck by the landslide processes, which should be constantly monitored.

The GIS adaptation to the existing database of the Kharkiv region landslide hazard massifs (LHM) facilitated the clarification of the following connections: "landslides density – area flooding", "the number of landslides – the amount of precipitation", "slump deformations – slope gradient", "slump deformations – seismic loads", "density of landslides – density of the road network". On the most part of the Kharkiv region territory, the LHM areas flooding, precipitation and anthropogenic factors have the dominant effects on the landslides evolution or activation.

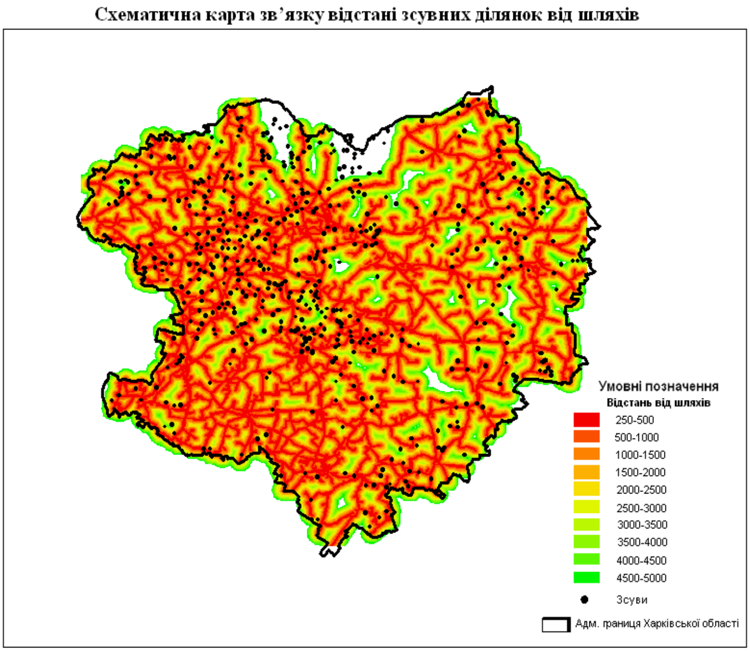

Fig. 5 – The distances from landslide areas to roads in the Kharkiv region

Firstly, a water table rise due to natural and anthropogenic factors is recorded almost wherever numerous landslides are observed. Anthropogenic factors can include the violations of sewer systems of buildings, low efficiency and hydrological imperfections of drainage systems, storm-water sewerage systems failures etc. Secondly, it is possible to observe the various economic activities with the significant violations of control standards (cutting of LHM slopes, lands ploughing for agricultural use in the vicinity of the landslide deformations manifestations, trees removal on slopes etc.). Thirdly, the dynamic impact on LHMs is rising because of the intensification of traffic density and transport speed, increase of transit freight traffic and respective loads on roads surfaces, reduction of the distances between roads and slopes etc. When processing the information available from the DB of landslide manifestations in the Kharkiv region districts, which has been obtained earlier, it became clear (fig. 6) that there was no valid correlation between the quantities of landslide areas and landslides.

That fact could have several reasons including the unreliability of landslides information, shifting (increase) of landslides activation, secondary factors of influence, stale data etc. All of that required the application of new approaches and modern information technologies to the collection and processing of LHM data etc., as well as the on-line acquisition of operational information. To solve those tasks the advanced software tools are necessary forthe assessment of landslide hazard at the local and regional levels based on a systemic combination of the analysis of unmanned aerial vehicles cartographic information, space images taken by means of Earth remote sensing, mathematical modeling results and GIS-technologies outputs. The new GIS model should contain multilayer information on the relief, slopes gradients, hydrographic network, roads, landslide areas and others.

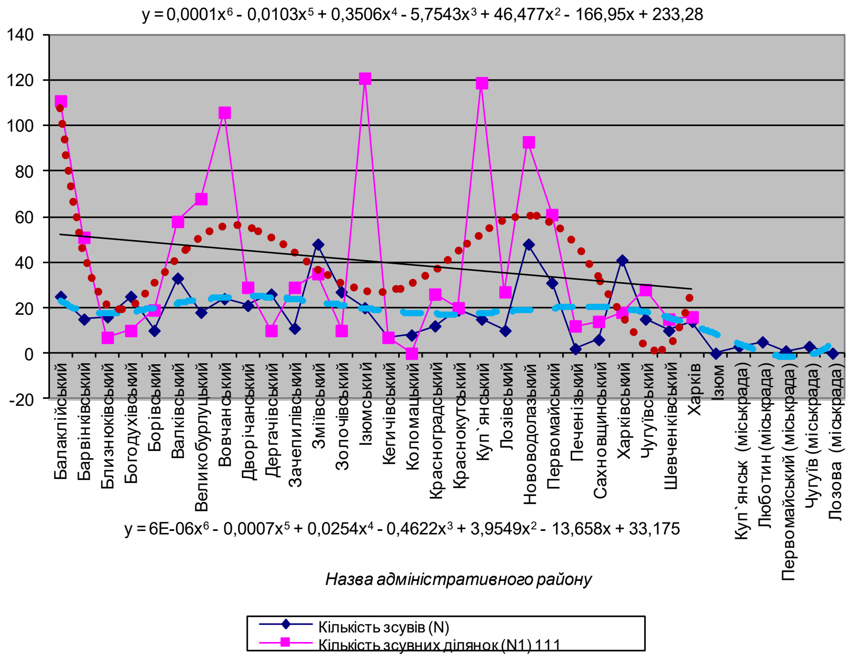

Fig. 6 – The count of landslides and landslide areas in Kharkiv region:
N – is a number of landslides; (N1) 111 – is a number of landslide areas.
Names of administrative regions:

Balakliiskyi	Derhachivskyi	Kupianskyi	Kharkiv
Barvinkivskyi	Zachepylivskyi	Lozivskyi	Izium
Blyzniukivskyi	Zmiivskyi	Novovodolazkyi	Kupiansk (city council)
Bohodukhivskyi	Zolochivskyi	Pervomaiskyi	Lubotyn (city council)
Borivskyi	Iziumskyi	Pechenizkyi	Pervomaiskyi (city council)
Valkivskyi	Kehychivskyi	Sakhovshchynskyi	Chuhuiv (city council)
Velykoburlut	Kolomatskyi	Kharkivskyi	Lozova (city council)
Vovchanskyi	Krasnohradskyi	Chuhuivskyi	
Dvorichanskyi	Krasnokutskyi	Shevchenkivskyi	

3.“**System for the UAV-monitoring of landslide slopes**”**.**

In 2017 O.A. Klimenkov defended his dissertation where the preliminary studies of the LH EWS units 1–4 using the unmanned aerial vehicle (UAV) were implemented at the theoretical and methodological levels. The application of new approaches and modern information technologies to the collection and processing of data on potentially dangerous landslide massifs etc. and the on-line obtaining of operational information require the improvement of existing software for the landslide hazard assessment at local and regional levels based on a systemic combination of UAV cartographic information analysis, satellite images taken by means of the Earth remote sensing (ERS), mathematical modeling and GIS technologies.

Despite the continuous improvement of the aerospace ERS tools, such aerospace photography has well-known methodological limitations, which are determined, first of all, by the impossibility of photographing at any time and in any place depending on the weather conditions and on account of satellites orbits geometry.

The preconditions for the UAV use as a new photogrammetric tool include the disadvantages of two traditional ways of the remote sensing data acquisition by means of space satellites (space photography) or manned aircrafts (aerial photography) (fig. 7).

a. The low resolution image from the Google Earth service

b. Superimposition of the aerial photo made from "Dozor-2" UAV

c. A high-resolution photo segment

Fig. 7 – Satellite observation data

Satellite observations allow the images acquisition with a publicly accessible maximum resolution of 0.5 m, which is insufficient for large-scale mapping (fig. 7a). Moreover, it is not always possible to find the cloudless photos in archive. In case of customized photographing, the promptness of data acquisition may be lost. The operators and distributors often do not exhibit the flexible pricing policies as to the relatively compact areas. Traditional aerial photography carried out from aircrafts (Tu-134, An-2, An-30, Il-18, Cesna and L-410) or helicopters (Mi-8T, Ka-26 and AS-350) requires high economic costs for maintenance and fueling, which leads to the increase of a final product value.

The application of standard aircraft systems is uneconomic in the following situations:

1. The photography of small objects and small areas. In these cases the economic and time costs of work organization related to a unit of photographed area significantly exceed the similar parameters of the large areas photography (particularly for objects at a considerable distance from an aerodrome);

2. The necessity to carry out regular photographing for monitoring the extended objects, including pipelines, transmission lines or traffic arteries.

It should be noted that the technology of aerial photography from UAV has been largely worked out. Currently, most of the existing and operating UAVs are intended for air reconnaissance and surveillance by taking photos and videos. Fig. 8 shows the real place of the UAVs among the existing shooting methods. The vertical and horizontal axes show the area covered by photographing and the operativity and relevance of the data received, respectively. As can be seen from the figure, the materials of satellite acquisition have the maximum coverage, but their applicability is insignificant. Sometimes the space images of certain territories are waited for months. The aerial photography and aerial laser scanning have a higher applicability and accuracy, but cover the smaller areas as compared to satellite acquisition. Also, both of the above mentioned methods of taking photos are expensive. The use of UAVs is justified in cases when it is necessary to quickly obtain accurate information about a locality at a small area. In addition, taking into account the cost of each of the solutions, UAVs get the very advantageous scoring and are optimal in some cases in terms of financial costs. Thus, the plus points of UAVs use are as follows: economic efficiency; possibility of taking photos from small altitudes and in the vicinity of objects and, therefore, obtaining the high resolution images; immediate imaging and the possibility of UAV usage in zones of emergency without any risk to the pilots' lives and health. The use of UAVs for solving the tasks of aerial surveillance of emergency areas (such as the monitoring of the Fukushima-1 NPP condition as of March 16, 2011 after the radiation accident) is the most cost-effective, safe and operational means of environmental monitoring.

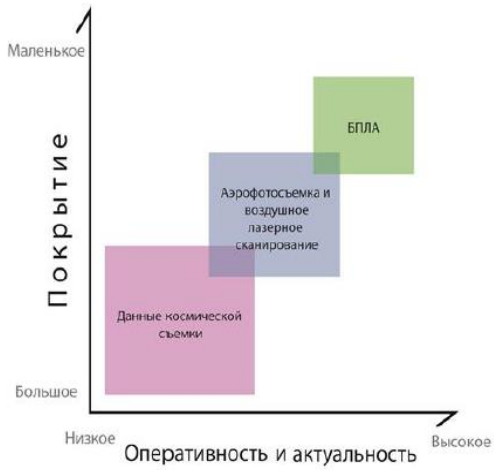

Fig. 8 – Comparison of existing methods for obtaining the Earth remote sensing data

Conclusions

1. The concept and practical implementation of the new integrated methodology of the EWS, which is based on the integration of modern monitoring technologies and comprehensive numerical simulation of the investigated object, is presented and described.

2. The effectual and efficient EWS shall perform four main sets of the following actions: the monitoring of the behaviour of an object under observation, i.e. data

collection and transfer, as well as equipment maintenance; the analysis and modeling of the investigated object under observation;warning, that is, the dissemination of simple and clear information about the object under observation; and the effective response of risk-exposed elements; full understanding of risks.

3. The following examples of practical implementation of the proposed integrated methodology for various construction objects or natural and man-made systems are presented: 1) the Central Livadia landslide system and Livadia Palace; 2) the system for landslide hazard areas monitoring in Kharkiv Region, and 3) the systems of early prevention of landslides with the use of unmanned aerial vehicles as the specialized systems for monitoring the deformations due to landslides.

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The article was received 04.09.2020 and was accepted after revision 16.12.2020

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СИСТЕМИ РАННЬОГО ПОПЕРЕДЖЕННЯ ПРО ЗСУВНУ НЕБЕЗПЕКУ В УКРАЇНІ

Анотація. Системи раннього попередження про небезпеку є ефективним інструментом для запобігання та пом'якшення ризиків, пов'язаних з виникненням різного типу загроз (зсувів у тому числі). У статті представлена і описана концепція та практична реалізація нової інтегрованої методології систем раннього попередження, яка заснована на поєднанні сучасних технологій моніторингу і всебічного чисельного моделювання досліджуваного об'єкта. Проектування, випробування та експлуатація систем моніторингу складних та унікальних будівельних об'єктів мають багато труднощів, досліджень та обґрунтувань, потребують системних знань у декількох сферах науки та техніки: будівництві, інформаційних технологіях, вимірювальних приладах, системах та алгоритмах обробки даних, програмуванні тощо. Основна концепція EWS, встановлених на зсувах, полягає в тому, щоб елементи, які піддаються ризику, особливо люди, що знаходяться недалеко від небезпечної зони, мали достатньо часу для евакуації в разі очікування неминучого колапсу. Тому дієва і ефективна EWS повинна включати в себе чотири основних набори дій: моніторинг активності об'єкта спостереження, тобто збір даних, передача та обслуговування обладнання; аналіз і моделювання досліджуваного об'єкта спостереження; попередження, тобто поширення простої і зрозумілої інформації про об'єкт спостереження; ефективна відповідна реакція елементів, схильних до ризиків; повне знання ризиків. Наведено приклади практичної реалізаії запропонованої інтегрованої методології для різних будівельних об'єктів та природно-техногенних систем: 1) Центральна Лівадійська зсувна система та Лівадійський палац; 2) система моніторингу зсувонебезпечних ділянок Харківської обл.; 3) система раннього попередження зсувів з використанням безпілотних літальних аппаратів в якості спеціалізованої системи моніторингу зсувних деформацій.

Ключові слова: методологія; раннє попередження про небезпеку; моніторинг; чисельне моделювання

Стаття надійшла до редакції 04.09.2020 і прийнята до друку після рецензування 16.12.2020

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