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Review article

METHODOLOGY FOR THE RISK MONITORING OF GEOLOGICAL HAZARDS FOR BUILDINGS AND STRUCTURES

Kachanov Sergey[1], Nigmetov Gennadiy[2]

[1] Russian – Serbian Humanitarian Center, Niš, Serbia

[2]All-Russian Research Institute for Civil Protection and Emergency Situations, Federal Centre for Science and High Technology

Correspondence: kacanov.sa@ihc.rs

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Abstract: In this article, technology for monitoring geological hazards is proposed to reduce the risk of the collapse of buildings and structures. The example considered in the article shows that the reduction of the landslide hazard of the soil massif on the slope can be achieved by: equipping drainage and storm systems that ensure the effective removal of groundwater; monitoring the state of the soil massif for the timely determination of dynamic and geophysical parameters and the exclusion of the occurrence of resonant phenomena from dynamic impacts; complex monitoring of the “soil-construction” system. Thus, the proposed technology of integrated soil-structure monitoring can provide timely warning of the geological hazard risk and thereby reduce the likelihood of destruction of buildings and structures by taking appropriate measures.

Keywords: dynamic geophysical monitoring, the safety of buildings and structures, geological hazard.

Introduction

Earthquake-caused disasters pose a variety of dangers to human society and are typically viewed as processes that occur from the interplay of natural and manmade systems (Cvetković et al., 2022; 2021; 2019; 2015). Currently, based in the development of a modern socio-economic system (Xuesong & Kapucu, 2019; Mano & Rapaport, 2019; Hussaini, 2020; Jha et al., 2021) and the growth of urbanized areas leads to the fact that more and more buildings and structures are located in geologically hazardous areas. In addition, due to the impact of dynamic and static loads from nearby construction and transport facilities, soil massifs located near or under buildings and structures may lose their equilibrium. The loss of the equilibrium and stability of soils leads to the appearance of subsidence, landslides, disruption of hydrological regimes, suffusions, karst phenomena, increased vibration and, as a result, an increased risk of collapse of buildings and structures. The authors developed the technology for dynamic-geophysical monitoring of the "soil-structure" system. With its help possible to see possible changes in the system when exposed to external factors. By using the developed technology (Kaur, 2020; Olawuni et al., 2020; Vibhas et al., 2019), it was possible to identify the cause of the destruction of load-bearing structures at the following facilities:

• residential buildings with sideway banks a and deformation cracks in Kaliningrad, which arose from the impact of vibration during bank protection works on river embankments;

• deformation of buildings in the Imereti Valley in the Adler region, which arose due to subsidence of foundation slabs relative to each other during the construction of Olympic facilities;

• deformation of a school building in Moscow due to exposure to increased vibration from a nearby metro tunnel;

• road in Ulyanovsk city due to the influence of inefficient slope drainage in the area of road slippage and increased vibration from railway transport and heavy vehicles (Fig. 1).

Figure 1. Sliding of the roadbed in Ulyanovsk city due to inefficient drainage and increased vibration from railway transport and heavy vehicles

Results and discussion

There are quite a lot of such examples in all countries of the world. In this regard, it seems appropriate, in addition to automated monitoring of engineering structures of buildings in geologically hazardous areas, to monitor geological hazards which can be the reason of building collapsing in the risk area. Such monitoring should be carried out both at the stage of exploration and construction, and after the completion of construction in potentially hazardous areas. The proposed technology of integrated dynamic-geophysical monitoring is a measuring and analytical system (Fig. 2 and Fig. 3), installed in the zone of possible geological hazards and consisting of: a computer with specialized program that allows user to receive and, according to special criteria, process and analyze digital data from sensors installed in the controlled area; multichannel analogue-to-digital converter (ADC); three-component acceleration sensors, tilt sensors, water level and pore pressure sensors; cable or radio channel data transmission system from sensors to ADC. The criteria developed by authors for assessing the stability of a soil mass using the results of dynamic geophysical observations make it possible to determine the onset of unstable soil equilibrium at an early stage from days to several hours. Oscillations are a sensitive parameter of the rigidity of structural systems. Vibrations of the soil mass, as well as structures, depending on its mass and rigidity.

Figure 3. Installation of a mobile system for dynamic and geophysical monitoring of a landslide-prone road section in Ulyanovsk city.

Figure 4. Data collection point for dynamic and geophysical testing of the impact of dynamic and background loads on the soil mass in the construction site area, residential complex under construction and the road at the landslide site.

The solution of the differential equation describing the oscillations of an object of length *l* (for example, a beam) looks like that [1-3]:

$$T_1 = \frac{l^2}{\pi^2}\sqrt{\frac{m}{EJ}}. \quad (1)$$

T_1 – object oscillation period, sec.;
l – length of object, м;
m – object weight, kg;
E – modulus of elasticity, Н/м^2;
J – object moments of inertia, м^4.
For a soil mass, the equation relating its vibrations to geometric and physical-mechanical parameters can be represented as follows:
$T_1 = 2{,}63 \times H\sqrt{\frac{\rho}{G}}$, where
ρ – density of the considered block of the soil massif;
G– soil mass shear module;
H – soil block height.

Therefore, by controlling the oscillation period of an object or a soil mass, one can control their rigidity, including the degree of the soil mass watering.

The data on the monitoring of the landslide-prone slope, made by the specialists of the All-Russian Research Institute for Civil Protection and Emergency Situations, are presented in Figures 5, and 6.

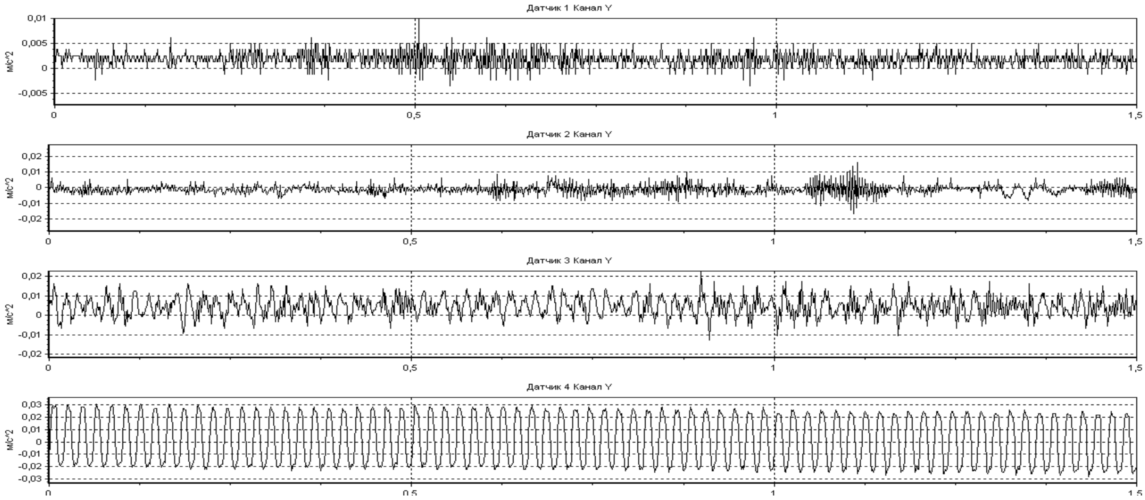

Figure 5. Acceleration of a landslide-prone section in Ulyanovsk city along the Y axis during the passage of a freight train

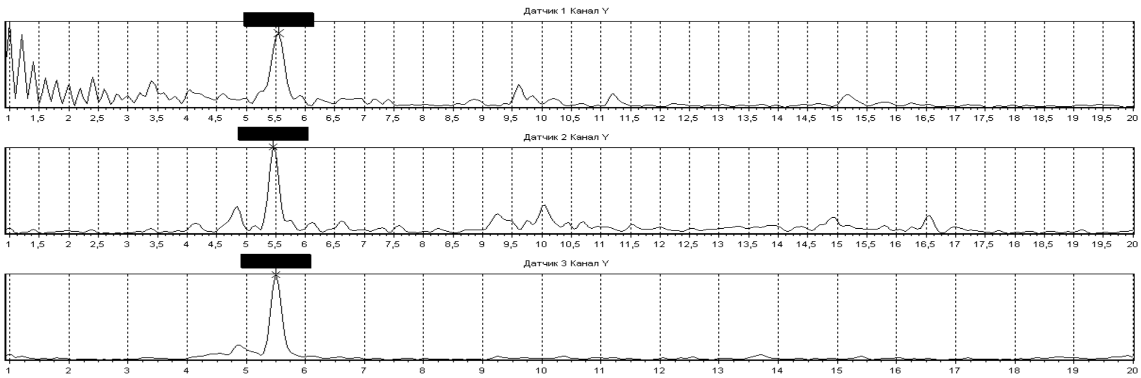

Figure 5. The spectrum of vibrations along the Y axis.
The appearance of dangerous low-frequency vibrations during the passage of a freight train on a landslide-prone section in Ulyanovsk city

Table 1. Results of dynamic-geophysical tests of the soil mass under different types of dynamic impact.

Object and types of measurements	A_x , м/sec²	A_y , м/sec²	A_z , м/sec²
Ground massif, background influences	**0,003** 0,015 0,03 0,004	**0,003** 0,01 0,01 0,004	**0,004** 0,005 0,005 0,003
Ground massif, trams passing	**0,004** 0,01 0,03 0,008	**0,004** 0,01 0,01 0,003	**0,004** 0,02 0,005 0,004

Ground massif, passing of 35 tons truck	**0,01** 0,042 0,03 0,006	**0,017** 0,05 0,02 0,006	**0,01** 0,09 0,005 0,002
Soil massif, pililng works with the 2.5 tons diesel hammer	**0,005** 0,022 0,022 0,15	**0,004** 0,02 0,015 0,3	**0,005** 0,01 0,01 0,2
Soil massif, piling 5 tons hydraulic device	**0,006** 0,045 0,03 0,52	**0,0041** 0,03 0,03 1,25	**0,0052** 0,015 0,01 0,6
Ground massif, train passing	**0,02** 0,01 0,02	**0,005** 0,01 0,015	**0,005** 0,0075 0,0075

Table 2. The period of natural oscillations of the soil massif in a wet state and after intensive drainage work:

№	The state of the soil massif in a moment of dynamic geo-physical measurements.	T_x, sec	T_y, sec	T_z, sec
1	Heavily flooded	0,078	0,078	0,078
2	After drainage installation, the soil is mild wet	0,05 Shift to high-frequency field	0,05 Shift to high-frequency field	0.05 Shift to high-frequency field

Analysis of the data presented in Table. 1 shows that the amplitude of accelerations of a landslide-prone slope caused by the passage of a railway freight train is 6.6 times higher than the background oscillations of the slope during passing of heavy vehicles. The periods of slope oscillations during the train and truck passing are shifted to the resonant frequencies (0.1 - 0.2) sec, which increases the risk of stability loss in the soil mass slope. The results of comparing the dynamic-geophysical parameters of the wetted soil massif (Table No. 2) with the soils after the drainage system installation, and the lowering of the groundwater level in the landslide-prone area show that the periods of natural oscillations along all measurement axes have shifted to the high-frequency field.

Comparison data show how sensitive dynamic and geophysical parameters are to the changes in the soil massif state. Efficiently performed work on lowering the groundwater level increased the rigidity of the soil mass, reduced deformation processes and increased the stability of the landslide-prone slope.Efficiently performed work on lowering the groundwater level increased the rigidity of the soil massif, reduced deformation processes and increased the stability of the landslide-prone slope.

The given measurement results show that the greatest accelerations and, consequently, displacements of the soil massif are because of dynamic loads created by the movement of freight trains and heavy vehicles. Maximum accelerations occur along the X-axis (along the Volga River in this direction, the maximum slippage of soils occurred). Accelerations arising from the impact of driven foundation piles during the building construction on the slope top are fixed in the landslide area at the background level and could not be the cause of its descent. The main reason for the landslide was a strong moistening of the soil massif, which led to its vibrations with a natural oscillation period of 0.078 s along all axes and resonant dynamic effects after passing trains and heavy vehicles.

Conclusion

The example considered in the article shows that the reduction of the landslide hazard of the soil massif on the slope can be achieved by: equipping drainage and storm systems that ensure the effective removal of groundwater; monitoring the state of the soil massif for the timely determination of dynamic and geophysical parameters and the exclusion of the occurrence of resonant phenomena from dynamic impacts; complex monitoring of the "soil-construction" system. Thus, the proposed technology of integrated soil-structure monitoring can provide timely warning of the geological hazard risk and thereby reduce the likelihood of destruction of buildings and structures by taking appropriate measures. Monitoring measurements will allow at the design stage to ensure the correct choice of rational engineering measures to improve the stability of the "soil-construction" systems, same as to ensure control over the effectiveness of their work at the operation stage.

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