PROBLEMS IN ASSESSING THE VULNERABILITY OF BUILDINGS AND STRUCTURES IN THE CONTEXT OF CLIMATE CHANGE

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Abstract

Already, we are increasingly encountering the consequences of dangerous climate impacts on buildings and structures. These effects are particularly evident in the thawing of permafrost, geological hazards, floods, mudflows, as well as forest and landscape fires. Of course, climate change also influences seismic and tsunami risks.
To plan protective measures for populations in hazardous zones in a timely manner, it is necessary to be able to predict the parameters of these dangers, assess the vulnerability of buildings and structures, and evaluate the risks to the population. By understanding the hazards, vulnerabilities, and risks, appropriate measures to reduce risks can be developed.

Keywords: technical condition of buildings, vulnerability of buildings, vulnerability of soils beneath buildings, individual risk for the population, risk reduction

I. Introduction

The most effective way to protect buildings from hazards associated with climate change and the reduced bearing capacity of soils is a reliable structural design of buildings and structures that provides protection against dangerous changes. However, it is not always possible to design and build buildings that are immune to vulnerabilities. Therefore, in order to prevent possible accidents, it is important to be able to quickly and reliably assess the technical condition and vulnerability of the "soil-building" system.

If we analyze what is more dangerous for the "soil-building" system, it is obvious that the most hazardous aspect is the emergency technical condition of both the building and the soil mass, as elements of an interconnected system [2].

Unfortunately, traditional methods of design, construction, and operation do not account for the possibility of errors at these critical stages. At the investigation stage, errors arise due to the limited capabilities of point-based drilling, as soil properties between boreholes are interpolated. Soil samples sent to laboratories for testing often lose their natural physical and mechanical properties during transport. During the design stage, errors are amplified due to inaccuracies related to soil conditions, which can be further exacerbated by the lack of consideration for climate change. Fast-paced competitive construction leads to underestimation of the importance of adhering to all design conditions, such as incomplete driving of foundation piles, poor quality of expansion joints, and inadequate implementation of soil paving and drainage around the building [3].

Figure 1: *A new framed residential building that has undergone significant deformation due to the thawing of soils in permafrost conditions*

II. Methods

For timely diagnostics of the technical condition of the soil mass and its suitability for construction, effective and accurate methods are needed that provide three-dimensional data about the structure of the soil mass and potential hazard zones within it. Such three-dimensional data on the stiffness of the soil mass can be obtained through its natural vibration frequencies. Heterogeneous hazard zones within the soil mass emit high-frequency acoustic noise. When building vulnerability decreases, the frequency of its natural vibrations also decreases.

A technology is required that can capture the frequency characteristics of the "soil-building" system and determine its stiffness, potential hazards, technical condition, and vulnerability based on frequency data. By identifying hazards and vulnerabilities, it is possible to determine potential consequences and the individual risk to the population using the geographic information system (GIS) "Extremum" [3, 4].

III. Results

The calculation of potential consequences from repeated strong impacts must take into account the possible decline in the technical condition and vulnerability of buildings. Currently, such a procedure is not provided in the GIS "Extremum." For the prompt assessment of the technical condition and seismic resistance of buildings, it is proposed to use the method of dynamic testing [11,13]. Based on the results of dynamic tests, the building database in the GIS "Extremum" can be updated.

In the GIS "Extremum," the current classification system for building databases is based on the MSK-64 seismic scale, and buildings are categorized into type A (constructed from local materials), type B (stone and block structures), and type C (seismically resistant, categories C7, C8, and C9). The proportion of building types in the database used for assessing the consequences of major earthquakes in certain areas is represented as percentages (see Table 3.2). [5]

Figure 2: *An example of mixed, dense development in the city of Istanbul on hilly terrain*

Table 1: *Example of database entry for buildings classified by type (based on data from 1999-2000, from the GIS "Extremum" database).*

City name	A/ Height, m	B/ Height, m	C6/ Height, m	C7/ Height, m	C8/ Height, m	C9/ Height, m
Nalchik	0,2/3	0,21/6	0,2/15	0,39/3	0	0

As seen from the example (see Table 1), in the examined city, according to data from 1999-2000, there are no buildings with seismic resistance of categories C8 and C9. This example makes it clear that the seismic resistance database requires constant updating. The seismic resistance data are tied to the seismic scale and provide only discrete values of seismic resistance without considering operational wear, meaning they do not reflect the actual seismic performance of buildings. The GIS "Extremum" database needs adjustments, and it can be used for preliminary analysis. The database can be updated either by decreasing or increasing the share of buildings in categories A, B, C6, C7, C8, C9, or by dividing the city's territory into separate areas with predominant seismic resistance values.

To assess the technical condition, stiffness, and seismic resistance of buildings and structures, it is proposed to use the "Struna" technology [11]. The essence of the method is based on the fact that through oscillations, the stiffness of the structure can be evaluated, and through stiffness, the technical condition and seismic resistance of the buildings can be assessed.

For evaluating possible resonance between the ground and the building, sensors are installed on both the ground and the building.

Stiffness deficiency is assessed using the following dependencies [4–8]:

$$\Delta fx = ([fx]2-fx2)\times 100/ [fx]2, (1)$$

$$\Delta fy = ([fy]2-fy2)\times 100/ [fy]2 , (2)$$

$$\Delta fz = ([fz]2-fz2)\times 100/ [fz]2, (3)$$

where fx, fy, fz are the values of the building's natural vibration frequencies obtained from dynamic tests.

[fx], [fy], [fz] are the standard natural vibration frequencies obtained from the design or calculated values.

Δfx, Δfy, Δfz are the stiffness deficiencies in percentages along the X, Y, Z axes (see Table 2).

Based on the obtained data on stiffness deficiency, the technical condition and seismic resistance of the buildings are determined [6].

***Table 2:** Percentage of stiffness reduction (square of the building's natural vibration frequency), depending on the category of technical condition*

Type of Structure	Percentage of Relative Stiffness Reduction of a Structure in Various Conditions				
	Very good	good	fair	poor	very poor
Reinforced Concrete Frame	0–25	25–43	43–57	57–71,4	71,4–100
Steel Frame	0–16,7	16,7–33	33–50	50–67	67–100
Brick	0–16,7	16,7–33	33–50	50–75	75–100
Wooden	0–20	20–27	27–40	40–67	67–100
For Other Types of Buildings and Structures, Soil Masses Beneath Buildings	0-10	11-30	31-60	61-90	

Dynamic testing is proposed to be conducted on characteristic typical elements of settlements with uniform building types. Data on seismic resistance (see Table 3) for each building element should be entered into the GIS database. The seismic resistance of buildings is proposed to be determined by the following formula:

$$A = \frac{4*\pi^2*\Delta d}{k_0*k_1*k_\varphi*\beta(T)*T^2} \quad (4)$$

where

Δd – the maximum allowable displacement of the building;

k_0 – coefficient accounting for the structural design features and its importance, K_0 [4];

k_1 – coefficient accounting for allowable damage, k_1;

$k\varphi$ – coefficient accounting for the dissipative properties of the structure, $k\varphi$;

β(T) – coefficient of the building's dynamic response;

T – period of the building's natural vibrations.

Based on the results of dynamic testing, knowing the category of technical condition, the probability of human injury can be determined

The individual risk of people being in damaged buildings in the considered hazardous area over the projected time interval, taking into account possible repeated impacts, is proposed to be calculated using the following formula:

$$Re_i(t)=P_z\times\sum_i^n m_i/(N_i\times T) \le [Re_i] \quad (5)$$

where

P_z - probability of the primary (or repeated) strong impact on the building;

m_i – estimated human losses in the event of failure of the "soil-building" system's bearing capacity in the considered i-th element of the area (building) after the impact [4, 10, 11];

N_i – number of people in the i-th element who fall into the danger zone leading to building damage;

T – the period during which the primary (or repeated) impact leading to building damage will occur;

$[Re_i]$ - risk norm of 10^{-5} .

The mathematical expectation of population losses is calculated using the "Extremum" geographic information system (GIS) [7].

Let us consider an example of assessing karst hazard for the soil mass in the area of a two-story building made of silicate brick. The building is two stories high.

Based on the results of dynamic-geophysical tests, the natural vibration frequencies of the soil and the building, as well as accelerations and damping decrements in the spatial coordinate system X, Y, Z, were obtained. Examples of measurements taken at the site in 2022-2023 are shown in Figures 3-4.

To assess the karst hazard of the construction site, the data on soil mass vibration frequencies in the low-frequency range (up to 20 Hz) and high-frequency range (from 0.1 to 400 Hz) were converted into a hazard parameter ranging from 0 to 10 points. The technical condition of the building blocks was evaluated by comparing the normative values and the squares of the natural vibration frequencies of the blocks obtained from the tests.

In Figures 3-4, the formation of karst hazards is visible in the form of high-frequency noises at frequencies of 60-120 Hz and periodic pulses, repeating every 0.5-1 second, with amplitudes exceeding the background microseismic vibrations by more than 10 times. To create maps of karst hazard for the site, dynamic-geophysical measurement data, depending on the values of the parameters and their level of "noise," were rated (Fig. 5).

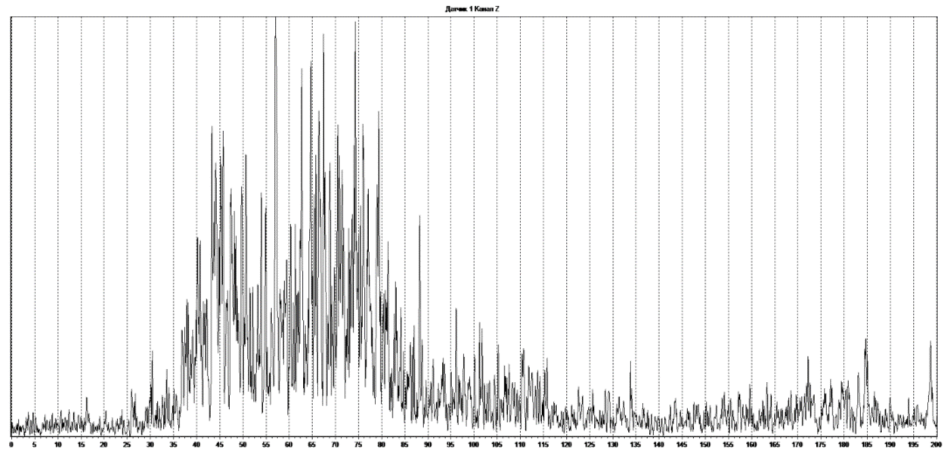

Figure 3: *Vibration spectrum of the "soil-building" system along the Z-axis, data from 2022.*

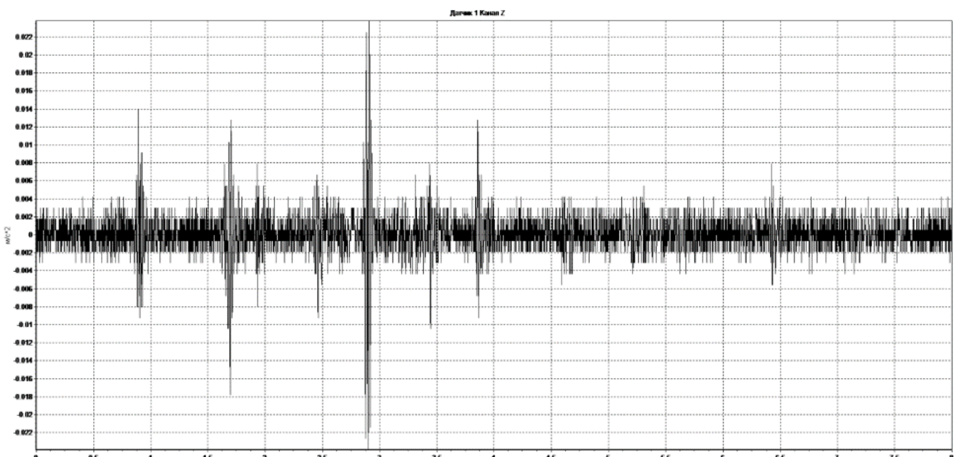

Figure 4: *Vibrations of the "soil-building" system along the Z-axis, data from 2022.*

Figure 5: *Zones of increased karst hazard (marked in red).*

IV. Discussion

The use of the dynamic-geophysical testing method allows for the rapid identification of stiffness deficiencies in the "soil-building" system and the assessment of building vulnerability. By knowing the vulnerability or technical condition of buildings, it is possible to determine the probability and expected losses, as well as calculate individual risk.

With the value of individual risk for the forecasted area, it becomes possible to plan risk reduction measures in a timely manner.

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