ASSESSING THE VULNERABILITY OF BUILDINGS TO THE THREAT OF KARST SINKHOLES

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Abstract

Karst sinkholes pose a great danger to people and infrastructure in many countries, so effective methods for assessing karst hazard are needed. However, there are currently no modern regulatory documents and methods for assessing the danger of karst sinkholes. The article describes the methods and provides examples of the application of several methods for assessing karst hazard, tested in real conditions in the karst zone of the Bryansk region.

Keywords: sinkhole formation, karst collapse, electrical resistivity tomography, ground-penetrating radar, dynamic-geophysical method, dynamic sounding method

I. Introduction

Sinkholes pose a serious danger to people and infrastructure. They can form suddenly and without apparent cause, making them unpredictable and difficult to predict.

Sinkholes can occur as a result of various factors, such as underground waters washing away soil and rocks, or natural geological processes. They can also be caused by human activity, such as construction or mining, the use of rural baths and toilets that discharge waters that are chemically aggressive to limestone rocks into the ground.

Karst sinkholes can have serious consequences: destruction of buildings and structures, damage to communications, and loss of life. They can also cause environmental problems, such as groundwater pollution or changes to the landscape.

To prevent the danger of karst sinkholes, it is necessary to conduct research and monitor geological conditions in areas where there is a risk of their occurrence. It is also important to take precautions, when constructing and operating facilities in such areas.

When designing buildings and structures in areas prone to karst sinkholes, it is necessary to take into account the geological features of the area and use special construction technologies. This will reduce the likelihood of destruction of buildings and structures when a karst sinkhole occurs. It is also necessary to identify developing karst sinkholes in populated areas in advance. [1]

II. Study area and geological setting

Bryansk region is located in the central part of the East European Plain. The length from west to east is 270 km, from north to south - 190 km. In the southeast of Bryansk region there are settlements, which are characterized by karst sinkholes. Mainly, research on karst sinkholes was conducted in the city of Novozybkov and the village of Vyshkov.

In the walls of the failure, a section of soil and vegetation layer with a thickness of 0.2 meters and clay rocks with a visible thickness of 6-7 meters will be exposed.

Below the observed clay rocks lie waterlogged sands, under which there is a layer of chalk deposits with interlayers of Upper Cretaceous marls. Karst and suffusion phenomena are associated with the area of distribution of Upper Kaman chalk rocks and Paleogene terrigenous deposits in the southwestern regions of the Bryansk region. Karst processes are confined to zones of tectonic disturbances and the associated increased fracturing of the chalk strata.

Increased fracturing of the chalk rock mass, chemical dissolution of chalk rocks by aggressive waters of Quaternary deposits, mechanical leaching of chalk rocks and removal of clayey chalk in the discharge area lead to the formation of karst-suffusion cavities and subsequent failures.

Active use of agrochemicals, runoff from large livestock complexes, failure to comply with sanitary protection standards cause pollution of the aquifer complex with nitrates, nitrites, chlorides, sulfates. Groundwater is especially poorly protected, and therefore its use by household wells is not always environmentally safe.

III. Methods

There are several challenges associated with detecting emerging sinkholes in urban areas. First, settlements are usually located near water bodies; thus, there is an abundant supply of groundwater near the village. Second, with frequent anthropogenic activities affecting geophysical detection. Thirdly, power cables are buried under the subsurface around the village, resulting in an electric surface current that affects some processes [2].

Therefore, accurate detection results cannot be obtained using only a single geophysical method [2], [3]. Therefore, we integrated multiple geophysical approaches, namely, dynamic-geophysical method (DGM), Ground-penetrating radar (GPR), dynamic sounding method (DSM), to improve the accuracy of detecting sinkholes.

Ground-penetrating radar GPR

The objective of the GPR survey was to determine the condition of the soil mass in the failure zone along longitudinal and transverse profiles. And also, to study the school territory for the presence of forming failures. The profiles are located both along and across the failure of the soil relative to the direction of the street. The purpose of the GPR studies was to identify zones of possible manifestation of karst and suffusion processes on radargrams [2].

GPR is based on the study of the field of high-frequency electromagnetic waves (frequencies from the first tens of MHz to the first units of GHz are used). The method is based on the difference in rock permittivity. The emitted pulse, propagating in the examined environment or object, is reflected from the boundaries at which the electrical properties change - electrical conductivity and permittivity. The reflected signal is received by the receiving antenna, amplified, converted into digital form and stored. As a result, from an ordered set of reflected signals, a section of the examined environment is formed, perpendicular to the plane of the georadar antennas, called the GPR profile [4].

The main quantities measured in GPR are the travel time of an electromagnetic wave from the source to the reflecting boundary and back to the receiver, as well as the amplitude of this reflection. Such interfaces in the studied environments are, for example, the contact between dry and water-saturated soils (groundwater level), contacts between rocks of different lithological composition, between rock and the material of an artificial structure, between frozen and thawed soils, between bedrock and loose rocks.

Dynamic sounding method DSM

For DSM, small-sized and powerful geological equipment will be appropriate. This method is used where clayey and sandy soils of any type of occurrence are studied. DSM specializes in obtaining complete and very accurate data on sandy and clayey soils.

DSM stages:

- Geological equipment is installed on a prepared site, appropriate equipment is selected so that its parameters meet the tasks and operating conditions;
- Then, using a hammer, the probe is driven into the ground;
- After a series of blows, the depth of the probe in the ground is measured;

- Sounding is completed when the probe reaches the design depth, or when, after a series of blows, the probe is immersed in the ground no more than 3-4 cm.

Dynamic geophysical method (DGM)

DGM is based on the assessment of the integral rigidity of a structure based on characteristic features and criteria that appear when processing the dynamic parameters of the "soil-structure" system.[5]

One of the features characterizing rigidity is the period or frequency of natural oscillations of the structure. Since the period of natural oscillations of the structural system of the structure is directly proportional to its mass and inversely proportional to its rigidity, then by measuring the frequency or period of natural oscillations, one can evaluate the rigidity of the structure. To evaluate the standard value of the period of natural oscillations of the structure, expressions obtained from the solution of differential equations describing its oscillation are used [6], [7]:

$$T=k\times\sqrt{(m/EJ)} \quad (1)$$

where

m – linear weight of the system, kg/m;

EJ – the rigidity of the system as the product of the modulus of elasticity and the moment of inertia, H×м2;

k – coefficient taking into account the structural design of the building.

IV. Results

As an example of the methods' operation, the data measured in the area of the school in the village of Vyshkov in the Bryansk region were taken. Since this zone was the most socially important, the largest number of measurements were made there by various methods. The main measurement methods were: dynamic probing, GPR and DGM.

GPR

In the surveyed area 12 GPR profiles were made. One of them is shown in Fig. 1.

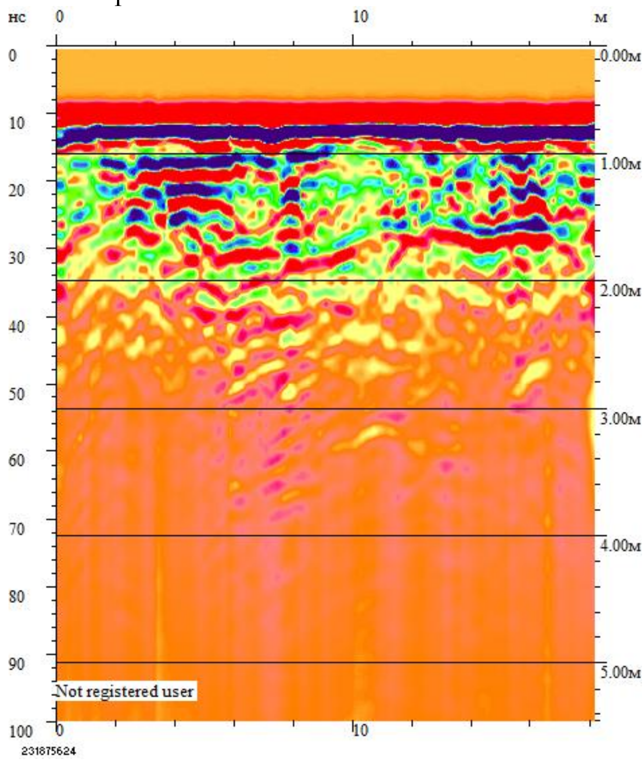

Figure 1: *GPR profile at the site of a possible karst failure*

On all georadar profiles the device does not give data below 3-4 meters, which indicates strong waterlogging of the soil. With the help of GPR, small anomalies were noticed and 2 zones of possible formation of a karst failure were identified.

DSM

DSM confirmed the high-water content of the soils. (Fig. 2) In addition, in places of possible karst failures, the dynamic probe easily entered the soil massif and showed weak soil resistance.

Figure 2: *Waterlogged soils on the extracted probe*

DGM

The dynamic parameters of the soil-building system include the frequencies of natural vibrations and the damping decrements along the X, Y, Z axes.

The frequencies characterize the rigidity of the system, the damping decrements show how the vibrations of the system are damped.

When assessing the soil mass, the researchers were guided by the following points:

- each type of soil of the same thickness is characterized by a certain level of the average weighted period (Taw);
- the values of Taw vary depending on the thickness and type of soil;
- the presence of a loose soil layer (arable land, etc.) causes the presence of high values of Taw in the immediate vicinity of the source of soil vibrations;
- at a distance of about 30-40 m from the source, the values of Taw approach the values of the prevailing period of vibrations (Tpr) for a layer thickness of 8-10 m ($Tpr=4H/\nu s$);
- with distance for soils of great thickness ($H>10$ m) at a distance of more than 40 m, an abrupt increase in Taw is observed, approaching the corresponding Tpr; moreover, for soils (thickness $H\approx8$-10 m) the increase in Taw with a distance of more than 30-40 m is small.

Thus, the study of average-weighted periods allows us to study both the physical and mechanical properties of soils and their resonance properties, determined by the equality of average-weighted and prevailing periods of oscillations.

Another indicator for searching for failures was the characteristic pronounced pulsation of the soil massif. (Fig. 3)

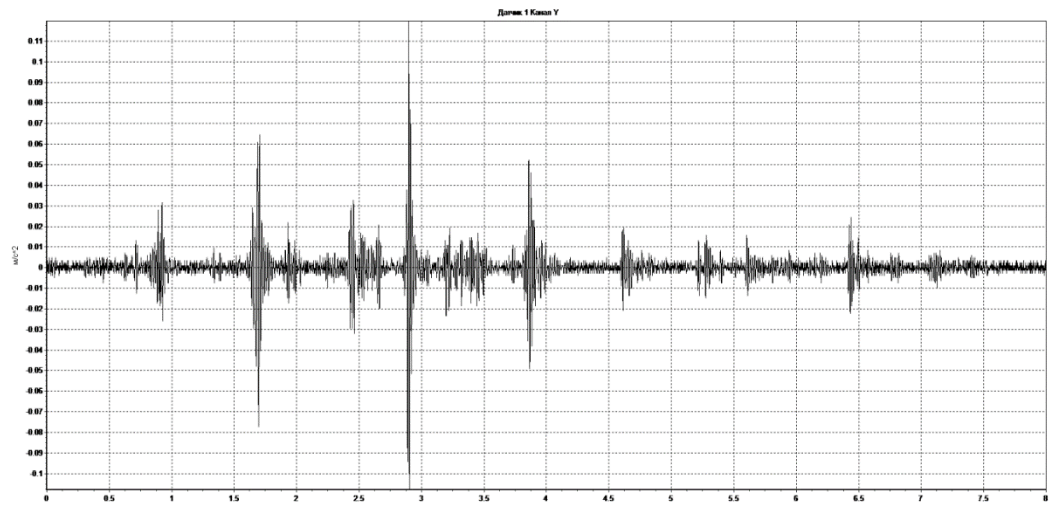

Figure 3: *Soil mass vibrations with pronounced pulsation*

Based on dynamic geophysical measurements (Table 1) and expert analysis, a map was constructed with zones of increased karst hazard. (Fig. 4)

Table 1: *The degree of karst hazard assessed using dynamic geophysical measurements*

Point	Fx, Hz	Fy, Hz	Fz, Hz	Degree of karst danger (in points from up to 10)
	100	105	100	9
2	30-100	3,75;60	41,648	6
3	38	39,2	0,15	8,5
4	5,25	4,35	5,2	9
5	34,6	94,8	0,15	8,6
6	92	92	20	7
7	89	89	60	5
8	65	114	0,15	6
9	100	100	100	8,7
10	6,3	7,25	0,15	5
11	110	105	0,15	6
12	185	180	0,15	5
13	125	110	100	6,5
14	112	100	110	8
15	5,4	2,85	0,15	4
16	100	100	0,15	7
17	100	90	100	6
18	100	12,8	12,8	4
19	65	64	64	3
20	12,8	12,8	12,8	2
21	12,8	12,8	12,8	5,7
22	10-25	10-25	10-25	4
23	9,95	12,8	12,8	3

Figure 4: *High karst hazard zones (red) at the school construction site, obtained from the results of processing DGM*

According to the dynamic geophysical soil tests in 2023, there is a threat of karst hazard at the building construction site (Fig. 4). The vibration spectra in the low-frequency region are equal to (2.3-7.25) Hz and correspond to waterlogged soils.

V. Discussion

During the surveys conducted in the karst hazardous area, a huge amount of data was collected. The data collection included various types of work, such as dynamic probing, ground penetrating radar and dynamic geophysical methods.

The collected data helped to better understand the characteristics of karst phenomena in this area and to develop recommendations for the safe use of the territory. They can also be used to predict possible changes in the karst system and to develop measures to prevent dangerous situations.

The main reason for the occurrence of karst sinkholes in the Bryansk region is the shallow depth of the chalk layer and its high-water saturation. And as a result of human activity such as the use of private rural baths and toilets, as the active use of agrochemicals, runoff from large livestock complexes, non-compliance with sanitary protection standards, pollution of the aquifer complex with nitrates, nitrites, chlorides, sulfates is caused. Groundwater is especially poorly protected.

In the course of the study of karst sinkholes by the three methods described above, DGM was found to be the most suitable. With the help of this method, anomalous areas of possible formation of karst sinkholes were identified.

The results of this method were subsequently confirmed by DSM. This method confirms places where the soil is greatly weakened, but this method is too point-based and labor-intensive. To assess karst hazard zones even in a small area, it is necessary to make a huge number of measurements with driving a titanium rod into the soil at each point. As an independent method, the DSM is not applicable separately from others.

GPR showed the most mediocre results. This method shows itself excellently for assessing soils to a depth of 10 m, but if the soils are not water-saturated. In this situation, the signal was jammed at depths of 3-4 m and the specialists were practically not able to see the anomalous zones.

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