Determination of underground voids in the surface of the earth section

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Abstract. One of the negative factors that affects the performance of various works on the Earth's surface are voids in the surface part of the earth's section. They are formed for various reasons. In most cases, these reasons are associated with irresponsible human activities. This can be excavation through adits, groundwater abstraction, or a breakthrough of underground utilities. In some cases, a disturbance in the ecological balance leads to the fact that the rivers go underground. Large areas of earth and sandstone are washed away. There is a danger of a collapse of the territory. Heavy rains are exacerbating this situation. These formed voids must be identified in a timely manner. Therefore, in places of their possible formation, it is necessary to constantly monitor the territory. The paper proposes an easy-to-use method for detecting these voids by imaging using refracted waves. For this, the collected data was processed using two different techniques. In the first case, the correlation of the first peaks on all seismograms is performed. This made it possible to obtain a depth-velocity section. The second method consists in reducing the travel time curves of the first refracted wave and obtaining a summarized seismic section. In this case, voids are distinguished by the loss of correlation of the axes of in-phase of the reduced time. This allows you to identify even small voids that form under the soil. With the deterioration of the ecological state, more and more voids are formed. To eliminate them, it is necessary to take prompt measures.

1. Introduction

A high level of man-made pressure on nature has led to a deterioration in the ecological situation [1-12]. This is the reason why soil is washed out, rivers dry up, and much more [13-18]. Deforestation also greatly affects the state of the Earth's upper surface, which is undergoing major changes. This is especially connected with the territories where there is a rapid construction [19-23] or mining [24]. The production of the latter forms large voids that are filled with water or liquefied gas [24-26]. Studies carried out by various methods [27-40] have shown that with temperature fluctuations, soil begins to move and karst appears along the perimeter of the plateau at some point.

Underground deep karst appears in the form of various voids or cavities, some of which are filled with loose material. Deep karst has been studied poorly enough, since it can only be identified during geological exploration or during the development of minerals. Currently, karst processes are quite active, as evidenced by the results of surveys in the southern and western parts of the Izhora plateau, when more than 100 fresh karst sinkholes from 1 to 10 m in diameter and 1 to 5 m deep were
discovered (Volosovsky municipal district). These failures pose a great threat to residents and field works [22, 23, 25].

Modern methods of voids study, based on the use of optical radiation [28-30, 41-44] and classical electromagnetic waves from various antenna arrays [33-40, 45, 46] have shown low efficiency. Especially from the point of view of forecasting the development of the situation. This creates difficulties in carrying out various works, for example, construction of buildings, laying of roads, underground communications and pipelines. This problem can be solved by applying the method of engineering seismic exploration, as the method of refracted waves (MRW), which can clearly identify the boundaries of karst formation, reveal its size and shape. This paper presents one of the practical studies by the method of refracted waves, carried out in the village of Sablino, Leningrad region.

2. Research methodology and instruments

The method of refracted waves is one of the methods of performing seismic exploration, which is based on the registration of waves refracted in the layers of the earth's crust, which are characterized by an increased speed of propagation of seismic waves, and also pass through them a significant part of the path.

In geotechnical surveys, MRW in combination with seismo acoustic methods is widely used to study the elastic and deformation properties of the section. This is due to the efficiency of field works and the simplicity of data processing. In real conditions, when the upper part of the section (UPS) of the study area is complicated by sharp horizontal and vertical drops in velocities, the presence of a complex relief and several refractive boundaries, the use of refractive waves is sharply complicated. But since there are no sharp elevation differences in the study area relief, the study was carried out outside an urban-type settlement, and the geological study of the area made it possible to assume an approximately constant UPS velocity, the research method was chosen using refracted waves. The advantages of which include the following: the ability to determine the boundary velocity in layers, low dependence on interference from multiple reflected and surface waves.

The study of MRW in practice requires special equipment. In our study, during the field works, a lightweight telemetric seismic station TELSS-3 was used. Its main characteristics, which influenced the choice of this particular station for work, are compactness and availability of use. With the help of TELSS-3 it is possible to carry out research on 2D, 3D and 4D technologies in the temperature range from -40 °C to + 70 °C both on land and in the "water-land" transition zones, regardless of landscape conditions. The components of the station are: four-channel digital modules connected in series by cable sections into a receiving line (streamers), an interface module connected to the operator's laptop via a USB cable. Each cable section is connected to 4 seismic receivers: "horizontal" or "vertical". To study the upper part of the section, "vertical" seismic receivers were used, which register the arrival of longitudinal waves, in contrast to the "horizontal" ones, which register the arrival of shear waves. As a device for exciting seismic waves, a surface source was used - a sledgehammer, which hit a metal plate lying on the surface of the earth.

One of the main advantages of a seismic station is the presence of a 32-bit analog-to-digital converter (ADC) in the system, which allows combining high speed and accuracy of conversion of input signals, which remain proportional to each other in the presence of various destabilizing factors [40-45]. Cable modules with 4 channels, to each of which a seismic receiver is connected, are connected by autonomous (telemetry) modules serving the 2 nearest seismic receivers to both left and right sides. This configuration of the device allows the station to be more independent of interference.

To describe the principle of operation, you need to know that the station has two modes of operation: diagnostics and registration of a seismic signal. In the field, the equipment was monitored, after which work was performed using the external synchronization mode of the "Signal" type.

The use of the telemetric seismic station TELSS-3 provides high noise immunity, and also makes it possible to increase the productivity of seismic operations.
3. Results of experimental studies and their discussion

The main task facing the engineering and seismic work was the task of determining the possible position of voids and weakened zones in the near-surface zone with a length of about 156 m. The cavity was defined in the depth interval from 3 to 6 meters. The outskirts of the Sablino village have a large number of underground workings, which are the result of sand extraction for construction. These cavities were considered to study the possibility of their separation by the method of refracted waves.

The seismic profile was located along the strike of one of these voids. A schematic map is shown in Figure 1.

![Figure 1. Schematic map of the profile location.](image)

The observation system was chosen as follows: the profile consisted of 20 telemetry streamers connected by means of modules. Each streamer is connected to 4 geophones, impacts were carried out through one geophones. Thus, 40 points of excitation (PT) were used in the arrangement. Before starting the direct data recording, the equipment was calibrated, the seismic channels were tested, and the necessary initial parameters were set.

In the region where the work was carried out, according to a priori data, it is known that the values of wave velocities in the section are in the range from 1400 m / s to 1600 m / s. Since the refracting boundary is quasi-horizontal, the boundary velocity is determined directly from the slope of the head wave hodograph. For the processing of practical data, the average speed of the head wave was set - 1500 m / s.

This made it possible to obtain images of the medium in the form of a reduced section of the MSW, shown in Figure 2. The obtained time section has two areas, indicated in Figure 2 by yellow circles, which have a different frequency character. Here, the mismatch of the in-phase axes is clearly traced, on the basis of which it can be assumed that there is a boundary between the two environments.

![Figure 2. Reduced time section.](image)
As a result of processing the initial data using the Easy Refraction module of the RadExPro program, a time section was obtained, which shows the boundary of the transition from dry soils (~1070 - 1300 m / s) to waterlogged (~2500 - 3000 m / s), which is confirmed by a sharp jump in speeds waves (Fig. 3). The module allows you to process hodographs of the first arrivals and build refractive boundaries using the to method (Reciprocal method).

![Figure 3. Time section obtained with the Easy Refraction module](image)

When comparing the obtained sections, the previously advanced assumption that in the areas indicated by yellow circles there may be a boundary between dry and waterlogged soils is clearly confirmed. Also, on the reduced time section, the correlation of the areas highlighted by yellow triangles with depressions in the section obtained using the Easy Refraction module is traced.

Based on this, we can conclude that the application of the MRW method makes it possible to see the refractive boundary between two media.

### 4. Conclusion

The time sections obtained using various processing methods showed that the use of MRW well reflects the presence of a groundwater boundary, and also makes it possible to confirm the assumption of the existence of underground voids in a given area. And also observe the dynamics of the process of karst expansion, which is quite difficult when using other methods.

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