Some Remarks on the Seismometric Experiments Taking into Account the Thickness of the Frozen Layer Soil

K. V. Kislov and V. V. Gravirov

Abstract Methodical studies of seismic wave propagation remain relevant in the shallow seismology, since the accuracy of the results depends on the appropriate analysis of the data. Monitoring of the thickness of the frozen ground is necessary for many scientific objectives and applications. The thickness of the frozen soil affects the accuracy of seismo-acoustic data in mining, seismo-acoustic logging and geological surveys used to study the structure of the geological formations, coal-seam fractures, assessment of the geological environmental stress state and shallow tomography. While the effect of the soil temperature on the velocity of seismic waves has been investigated well the seismic waves attenuation affected by the thickness of the frozen Earth top layer needs to be investigated further. No sufficient data is available of the electrical properties of the frozen top layer of the Earth.

Keywords Freezemeter · Frozen soil layer thickness · Seismic survey · Monitoring · Seismic signal

1 Introduction

In Russia, about 11 million km^2 of the territory are covered with permafrost. Besides the fact that the thickness of the permafrost is uneven (due to different thickness, lenses and interlayers, taliks), the permafrost is also a dynamic system that follows the seasonal and climatic changes. Almost throughout the rest of the country, the active layer of the soil undergoes periodic freezing and thawing.

It is widely known that seismic wave velocity depends on the temperature of the soil. It was pointed out that the most significant velocity variations happen when the

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Earth ground freezes or thaws. These phenomena happen due to the water-ice-water phase transitions within rocks of different dispersity and lithology. But there is a lack of understanding of seismic waves attenuation which depends on the depths of the frozen layer. The thickness of the frozen layer affects the accuracy of seismo-acoustic data in mining, seismo-acoustic logging, and geological surveys used to study the structure of geological formations, coal-seam fractures, assessment of the geological environmental stress state and shallow tomography. The electrical properties of frozen soils have to be further investigated. The calculated results of the average depth of frost penetration or the measured maximum depth of the frozen layer for a given area are often inaccurate.

The monitoring system was created to obtain geophysical data related to the thickness of the frozen top layer of soil. The general principles of solving the problem are described below. Promising scientific experiments are a detailed study of the propagation of seismic and acoustic waves in the near-surface layer of the Earth; electric properties of frozen soil of different thickness etc. It is very important and highly relevant issue for seismic exploration and shallow geophysics in general, for improving the resolution of seismic stations, studying seismic noise and for seismic microzoning of areas with frozen soils [1]. Monitoring of the thickness of the frozen soil could be used for the data processing in the structural seismology for corrections (including dynamic correction) that take into account the heterogeneity of the upper part of the geological environment [2]. Methodical studies of seismic wave propagation in shallow seismology remain relevant as the correct interpretation of the data depends on the accuracy of observations. The influence of subsurface on seismic signal can be so severe that static corrections are inadequate [3–5].

2 Monitoring of the Frozen Layer

It is necessary to build a measuring system that will be capable to collect accurate data vertically, at required time intervals, remotely and completely automatically. Such system will provide averaged data for large areas and, if necessary, highlight local features, and verify the correctness of the theoretical values of the frozen layer thickness. The frozen layer can be well below the ground surface when the top layer is melted due to positive daytime temperature, such as in spring and autumn. In this case the thickness of the frozen layer is the main factor. The distance from the surface of the Earth is a secondary factor. It should be noted that measurements would not make sense if they are recorded in a single prepared place. Measurements have to be taken with care covering a large area with sensors arrangements to cater for different conditions. The measurement time interval of a few hours is clearly too long. We must have a measuring system consisting of several groups of sensors (thermistor chains), located at a considerable distance from each other and under different conditions (different types of ground, self-ventilation of the site, vegetation, shading). The maximum depth of soil freezing for the Moscow region is known. The size, maximum for 10 years of measurements, was measured by the Danilin freezemeter [6] at an open, snow-cleaned site. It is 140 cm. If a depth of snow is 50 cm, the thickness of the frozen layer is reduced 3–5 times. Therefore to simplify the implementation of the freezemeter model, we have chosen the monitoring depth of no more than 30 cm at all. Other technical requirements for monitoring system were formalized as follows:

1. Measurements have to be carried continuously; the sampling time intervals should be set up from 10 min to 12 h.
2. The depths resolution should be at least 2 cm.
3. The sensitivity of the temperature sensors should be accurate to at least 0.5 °C.
4. The number of buried probes in the thermistor chains should be 4 or greater; the distance between probes should be at least 2 m.
5. A hardware or software averaging of the thickness of the frozen layer should be performed for each thermistor chain and, if necessary, for all chains.
6. The measurements should be carried out remotely, without removing the sensors from boreholes, that is, without disturbing the thermal regime, snow and vegetation.
7. The buried probes should have a lower thermal conductivity than the surrounding soil.
8. Reduction of the number of commuting wires should be welcomed.

3 Freezemeter

The electronic freezemeter has been developed and its production prototype has been manufactured according to the present requests [7]. An original technology was used, which allows to avoid the difficult and expensive digital systems by applying a translation of the measured analog input signals from thermosensors to a digital form without any analog-to-digital converters. The block diagram of the electronic freezemeter is shown in Fig. 1.

Working with almost any new system naturally creates methodical difficulties. For example, if seven sensors of the thermistor chain are placed in a forest, which also forms a thick layer of snow, and the eighth sensor is placed in the open area, then how will this reflect the fact that 7/8 of the study area is covered with the forest? How to locate the sensors and how to average the thickness of the frozen layer are the main questions. Linking the measurement results to the synthetic maps can help. The main source of heat entering the Earth ground is the radiant energy of the Sun, which is absorbed by the soil surface. The heat is translated to the underlying layers, and some thermal to heat the air and evaporate water. If you know the amount of incoming heat and the basic characteristics of the Earth ground, then it is quite simple to calculate the temperature at different depths. Such algorithms take into account the type of Earth soil, its humidity and density, the thickness of the snow cover, the latitude, as well as variations of the air temperature. The theoretical calculations are verified by experimental measurements at one or two points using pull-out thermometers [8].

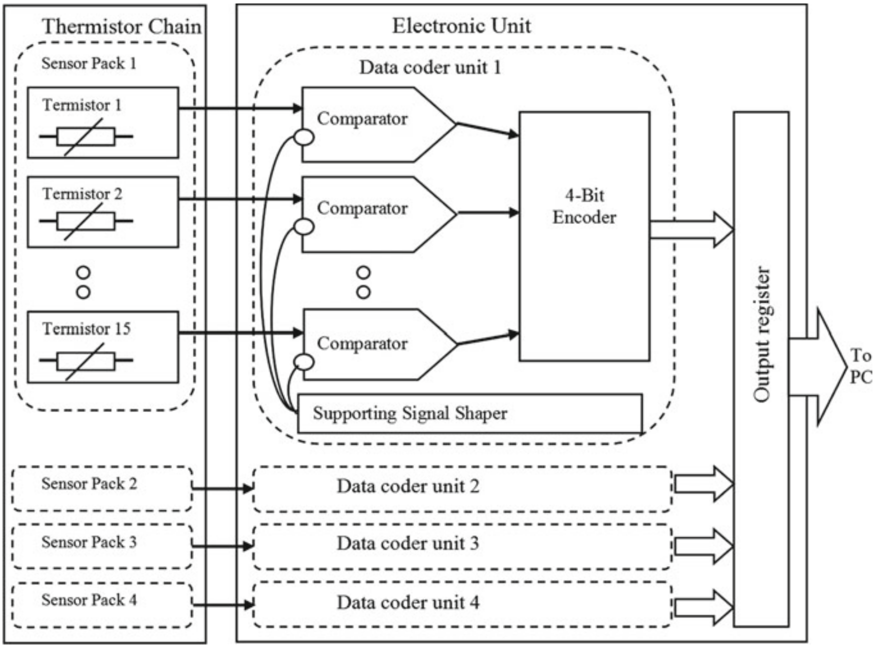

Fig. 1 The block diagram of the electronic freezemeter ELFREEZMETER-2

There is also the possibility of interactive calculations of the ground temperature distribution [9]. These calculations could be used for drawing the synthetic maps of up to 1 km × 1 km grid. Such calculations allow to obtain an assessment of the soil current state, but and also to predict its state according to average climatic changes in temperature and humidity. This data is useful, for example, for estimating the heat balance between the Earth ground and the atmosphere. It is clearly necessary to have more detailed and accurate experimental data of monitoring of the thickness of the frozen layer, to achieve the above-mentioned scientific and applied purposes.

4 Technique of Experiment

Thus, for collecting the informative data on the thickness of the frozen layer, it is necessary first of all to determine the required range of frequencies of seismic waves. From the wavelength range we can find the necessary spatial resolution. Based on the dynamic range of the seismic phenomena under study, we can determine the meaningful variation of the frozen layer thickness and the necessary resolution of the freezemeter in the vertical direction. Further planning of the experiment is impossible without prior knowledge of the territory where the experiment will be undertaken. In order for the freezemeter data to be representative, the thermistor chains and their buried sensor blocks have to be arranged according to local conditions. These include: terrain, maximum seasonal freezing of the ground, soil types, their moisture and density, vegetation cover. The conditions must be known with the above spatial resolution.

Researchers may need different types of data. In a simple case the designing of a seismic experiment requires the knowledge of average thickness of the frozen layer over the entire territory. In this case you will need to choose a location for the installation of a single thermistor chain, which has to be placed according to the "average" concept. Several buried packages of the sensors will prevent the monitoring of random errors and smooth out local conditions such as vegetation type, and thickness of the snow layer, insolation and ventilation of the site.

It may be necessary to monitor the frozen layer between the reception and excitation points of seismic signal and/or examine an object. In this case, several thermistor chains may be required, each of which is responsible for a certain average area. For a long-term monitoring, relationships between the thicknesses of the frozen soil layer at different sites can be found, and hence the amount of thermistor chains can be reduced.

5 Conclusion

First tests of the mockup have confirmed the operability of the proposed instrument and method. As expected, the thickness of the frozen soil layer and the dynamics of the freezing depth are very much dependent on the conditions of the sensor installation site (ground type, its moisture and density, thickness of a snow, vegetation cover, insolation and ventilation). One of the buried sensor packs was installed next to the Danilin freezemeter, under the same recommended conditions, i.e. on the site cleared during the whole period of measurements from vegetation and snow at a distance equal to twice the standard depth of seasonal soil freezing. In the initial period of registration, the instruments' responses were exact coincidence. In the later period the freezing point in this place fell below the measuring range of the mockup. At the same time, the buried sensor pack, which is protected by vegetation and snow, showed much less freezing. The maximum noted difference has made 20% of thickness of a frozen layer. Results on the temperature processes dynamics are also obtained. For example, when there was a sharp increase in depth of frost penetration (about 10 cm per two days) at the open place (see Fig. 2), the sensor, located under the protection of trees and snow of more than a meter thick, did not notice any dynamics.

This reaffirms the urgent need for detailed planning and preparation to monitoring and conducting of experiments.

The above considerations can be used in experiments in any region where the thickness of the frozen layer may affect the data for any type of seismic waves and other characteristics of geophysical fields.

Fig. 2 The buried sensor pack. We had to use the air lines, because under the snow the wires were attacked by mice

In our case, we considered seismic signals, excited by passing heavy trucks (the road was at a distance of 300 m from the registration point) and by freight weighing 500 kg falling from height of 4 m (at a distance of 350 m from the registration point). The frequency range of the seismic signal of interest was from 20 to 100 Hz. It would be wrong to expect that in this range, with such small thickness of the frozen layer (this year the depth of freezing between the points of signal excitation and recording did not exceed 26 cm) there would be any noticeable influence of the presence of the frozen layer on the experimental results.

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