Application of the GPR Method for Engineering and Survey Work in Petropavlovsk-Kamchatsky City

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Abstract. The use of geophysical research methods in engineering and geological surveys qualitatively increases the geological information content of the studied area. The article shows the experience of using the GPR method at various construction sites in Petropavlovsk-Kamchatsky City. All these results are presented on the example of work on objects of different levels of social significance. Thanks to the data obtained, it becomes possible to clarify soil conditions and make the right decisions when designing construction objects, as a result of which engineering surveys become less costly.

1. Introduction

In recent years, engineering and geophysical research are increasingly called methods of shallow geophysics, since the list of objects and research methods has significantly expanded. One of the known methods of shallow geophysics is the GPR method. Its advantage are versatility and low cost of performing instrumental studies. It allows the use of georadars for solving various problems. The GPR method has been successfully used to map the top of bedrock disturbed by tectonic movements and to study the stratification of the near-surface strata of loose sediments. Georadar research makes it possible to identify vertical zones of increased heterogeneity and fragmentation of rocks, as well as waterlogged areas in loose sediments.

Snowiness, swampiness, soil freezing, high seismicity are some of the Kamchatka Territory features. This determines the importance of an accurate survey of the geological conditions of construction sites to ensure safety in future infrastructure design.

The first experience of using the GPR method for solving geological problems in Kamchatka was in 2004 [1]. There was also an experience of using the method in the study of faults associated with crustal earthquakes in the area of the Poperechnaya River in South Kamchatka, and further, in the study of active fault tectonics in the south of Central Kamchatka [2, 4]. At present, the GPR method is actively used in engineering and geological surveys to clarify soil conditions in Petropavlovsk-Kamchatsky City.

The reliability of the obtained results, presented in the article, is confirmed by the large amount of material used in the work; the duration of the research; practical applications of research results; specific goals and tasks of the research; a combination of qualitative and quantitative analysis of research results.
2. Research methods
The GPR method was performed using the OKO–250 georadar (center frequency 250 MHz, sounding depth 6-10 m, resolution 0.35 m). A detailed description of the device and recommended measurement parameters are presented in the article [3].

3. Research results and discussion

![Figure 1](image.png)

**Figure 1.** General layout of the objects of research in the area of Petropavlovsk-Kamchatsky City and the surrounding area. 1 - valley of the Avacha river; 2 - the coast of the Mokhovaya Bay; 3 – Chavycha Cape; 4 - a building on the coast of Avacha Bay (KGBU "Kamchatka Regional United Museum").

3.1. The structure features of the sedimentary strata of the Avacha river valley
In this area, in the event of a strong earthquake, one should expect the destruction of infrastructure and part of the roadway connecting Petropavlovsk-Kamchatsky City with other settlements (Figure 1). Moreover, detailed research in the considered area have not been performed for many years, though its need is called for the change in the normative, initial seismicity in the Elizovsky region in connection with the approval of new maps of the Russian territory general seismic zoning (OSR - 97). As a result of GPR profiling, radarograms were obtained along profile No. 1 and No. 2. By the correlation of the in-phase axes on the radarogram along profile No. 1, 2 boundaries can be identified obviously (description from the top down). The first boundary is recorded at times of the order of 80 ns, which corresponds to a depth of about 3 m at an electromagnetic wave propagation speed of $V = 3.75 \text{ cm} / \text{ns}$ and dielectric constant $E = 64$. When comparing the engineering-geological section, coarse-grained sands occur at this depth. The second boundary is recorded at times of the order of 100 ns, which corresponds to a depth of about 4 m at an electromagnetic wave propagation speed $V = 5 \text{ cm} / \text{ns}$ and a dielectric constant $E = 36$. By the correlation of the in-phase axes on the radarogram of profile No. 2, 4 boundaries can be distinguished (description from the top down). The first boundary is recorded at times of the order of 50-60 ns, which corresponds to a depth of about 2 m, the velocity of propagation of an electromagnetic wave is $V = 4 \text{ cm} / \text{ns}$, and the dielectric constant is $E = 56$. The second boundary is recorded at times of the order of 80 ns, which corresponds to a depth of about 3 m and gradually sinks to a depth of 5 m, the velocity of propagation of an electromagnetic wave is $V = 3.75$...
cm / ns, and the dielectric constant is $E = 64$. The third boundary is recorded at times of the order of $110 \text{ ns}$, which corresponds to a depth of about $6 \text{ m}$ and gradually sinks to a depth of about $7 \text{ m}$, at the speed of propagation of the electromagnetic wave $V = 5.4 \text{ cm / ns}$, the dielectric constant is $E = 30$. The fourth boundary is visible at times of the order of $160 \text{ ns}$. This corresponds to a depth of about $9 \text{ m}$ at an electromagnetic wave propagation velocity $V = 5.6 \text{ cm / ns}$ and a dielectric constant $E = 28$. Worth noting is the fact that a slight change in the water content in sand and in soils leads to large changes in the dielectric constant, which affects on the informativeness of radarograms. The results obtained were used for the reconstruction of the territory where objects of increased social significance are located.

3.2. Research of landslide-explosive deposits of Avachinsky volcano on the coast of Mokhovaya Bay

The northern part of Petropavlovsk-Kamchatsky City and settlements between the regional center and Elizovo City are located on avalanche deposits of a landslide-explosive origin, formed at the end of the Pleistocene during the destruction of the building of the Ancient Avachinsky volcano (Figure 1). Significant volume (16 - 20 km$^3$), roll-down height $H (> 3 \text{ km})$ and path length $L$ (about 30 km) at the usual value of the ratio $H / L = ~ 0.10$ for such debris avalanches arouse great interest in studying their structure and composition. It is necessary to clarify the spatial distribution of the various lithological types of deposits that make up the hills and depressions on the surface of the avalanche. In addition to the theoretical value (clarification of the genetic characteristics of the formation of deposits), the solution of this issue is of great practical importance, since determines planning restrictions in the placement of buildings and structures. As a result of processing the radarograms, it was established that almost everywhere the considered deposits are covered by a cover (thickness from 0.5 to about 10 m) of younger Quaternary deposits, which are clearly distinguished on the radarograms. In the structure of the depressions, mainly rubble-rubble deposits with the inclusion of individual blocks are involved. In the valley of the streams, peat deposits were exposed. The results obtained were used to reconstruct the study area.

3.3. Clarification of the landslide hazard at Chavycha Cape

In the Petropavlovsk-Kamchatsky City, the sewage treatment plant (MUP KOS «Gorvodokanal») at Chavycha Cape was commissioned in December 1989 (Figure 1). About 25 thousand cubic meters of urban sewage per day flows through the filters of the KOS. This is almost 25% of all effluents flowing into Avacha Bay. The need to reconstruct the KOS at Chavycha Cape is due to an increase in wastewater consumption and increased requirements for the quality of treated water. As a result of the work and the subsequent analysis of the collected material, leaks from silt fields were revealed at the researching site, one of which leads to the discharge of groundwater in the form of seepage from a crack in the coastal scarp. And also the body of an ancient landslide, represented by gravelly soil, the body of an ancient landslide, represented by gritty soil and the slope of a paleo-arm.

Analysis of seismic conditions and landslide hazard of the treatment plant site revealed:

1. Landslide hazard in this area is quite high. The location of two landslide bodies, as well as the slope of the paleo-arm, were established.

2. Based on the results of the work, the presence of landslide processes in the eastern segment of the southern part of the site is established.

3. Clarification of the seismic conditions of the territory made it possible to conclude that the seismicity of this site is 10 points in the western part and 9 points in the southeastern part of the slope. When constructing in areas with filled soils, it is necessary to remove them, including macroporous soils, otherwise it is possible that not only soils, but also buildings slide down the slope.

All the obtained results were used for the reconstruction of this area.
3.4. Clarification of engineering and geological conditions for the reconstruction of the building on the coast of Avacha Bay

Along the coast of Avacha Bay, there are many buildings and buildings of Petropavlovsk-Kamchatsky City (Figure 1). The task is to clarify the lithological structure of loose deposits for the reconstruction of the building of the KGBU "Kamchatka Regional United Museum", Leninskaya Street, 20. On radarograms obtained by GPR profiling on three profiles with a total length of 122 m, a layered stratum of loose deposits is well manifested to depths of 2 - 3 m. According to the obtained data, on two profiles 1 and 2, loose deposits are not disturbed, the layers lie horizontally. Presumably, these deposits are represented by fill soils, which were filled up here during the planning of the territory. Down the slope (to the west of the museum building), a shallow (2-3 m) and not wide (about 20 m) hollow (profile 3) is clearly visible in the relief, it is also visible above the ledge cut into the slope when planning the territory. The building itself is located on a leveled area formed by planning and filling this hollow. To the north and south of the site there are other hollows, similar to those described on the territory of the museum. The northern hollow is crossed by GPR profile 3, and it can be seen on it that the thickness of the sediments that fill it is small (5 - 6 m). The troughs are most likely not alluvial, but proluvial, i.e. sedimentation occurred during spring snowmelt and autumn showers. Subject to the recommendations on compliance with the drainage conditions of the overlying slopes and preservation of the underlying slopes (do not cut them), the overall stability of this slope and the stability of the foundation of the museum building is ensured.

Thus, the stratum of loose deposits is the upper structural level, consisting of loose layered deposits of various genesis: bulk, marine, lagoon and others, up to a few tens of meters thick.

4. Conclusions

The use of the GPR method provides a higher resolution in the upper part of the section. This allows to see, for example, the localization of small and closed irregularities common in the near-surface part of the soil section. Some important infrastructure facilities are located on slopes with seismic and landslide hazards. The use of the GPR method in a given area makes it possible to identify a landslide body, paleo-arm slopes, as well as waterlogged areas. For an accurate interpretation of radarograms, a description of geological sections and wells in a given area is used. Snowiness, swampiness, soil freezing are some of the features of the Kamchatka Peninsula. However, this does not significantly affect the limitations in the use of the device and its operation. The GPR method also makes it possible to assess the moisture content and soil erosion. Thanks to the obtained data, it becomes possible to make the right decisions when designing construction projects in the Petropavlovsk-Kamchatsky City.

The change in the dielectric constant and the speed of propagation of electromagnetic waves for soils along the objects of the research in the area of the Petropavlovsk-Kamchatsky City and the characteristics of various geological structures in the wave pattern of the radarograms obtained at the researched objects of Kamchatka are respectively presented in Tables 1 and 2.

5. References

[1] Abkadyrov I F and Bukatov Yu Yu 2004 The first experience of using the OKO GPR in Kamchatka Vestnik of the Kamchatka Regional Organization Educational and Scientific Center. Series: Earth Sciences No 4 pp 125 - 129

[2] Kozhurin A I Ponomareva V V and Pinegina T K 2008 Active fault tectonics of the south of Central Kamchatka Vestnik of the Kamchatka Regional Organization Educational and Scientific Center. Series: Earth Sciences No 2(12) pp 10 - 27

[3] Pavlova V Yu 2013 Experience with the device georadar "OKO-250" on the Kamchatka Peninsula Sensors and systems (Moscow: Sensidat-Plus) No 4(167) pp 55 - 58

[4] Tarabanko A V 2007 Application of GPR in the study of faults associated with crustal earthquakes in the area of the Poperechnaya River (South Kamchatka) Vestnik of the Kamchatka Regional Organization Educational and Scientific Center. Series: Earth Sciences No 1(9) pp 154 - 158
### Table 1. Change in the dielectric constant and the speed of propagation of electromagnetic waves for soils over the objects of the research in the area of Petropavlovsk-Kamchatsky City.

| №  | Description of soils                                      | Dielectric constant value (E) | Electromagnetic wave propagation velocity value ($V_{эмв}$) | Note                                                                 |
|----|----------------------------------------------------------|-------------------------------|------------------------------------------------------------|----------------------------------------------------------------------|
| 1  | Crushed stone                                           | 3.92 – 9                      | 10 – 17.06                                                 | Changes in indicators by the degree of water saturation (from lower to higher) |
| 2  | Crushed rock with sandy loam up to 40%                  | 17.06                         | 7.27                                                       |                                                                      |
| 3  | Crushed stone soil with sandy aggregate wet 30-35% with the inclusion of lumps up to 10% | 7.56                          | 10.9                                                       |                                                                      |
| 4  | Coarse sands                                             | 28 – 64                       | 3.75 – 5.6                                                 | Changes in indicators by the degree of water saturation (from lower to higher) |
| 5  | Silt black flowing peat                                 | 9.86 – 16                     | 7.5 – 9.54                                                 | Changes in indicators by the degree of water saturation (from lower to higher) |
| 6  | Gritty soil with sandy aggregate and varying degrees of water saturation | 4.41 – 31.4                   | 5.33 – 14                                                  | Changes in indicators by the degree of water saturation (from lower to higher) |
| 7  | Sandy loam with lumps up to 5%                           | 8.01                          | 10.6                                                       |                                                                      |
| 8  | Eluvium of weathered diabases, destroyed to crushed stone| 7.84                          | 10.71                                                      |                                                                      |
Table 2. Characteristics of various geological structures in the wave pattern of radarograms obtained from the objects of the research in the area of Petropavlovsk-Kamchatsky City.

| №  | Geological structure          | Type of wave pattern on the radarogram | Description of the wave pattern on the radarogram                                      |
|----|-------------------------------|----------------------------------------|----------------------------------------------------------------------------------------|
| 1  | Proluvial fan                 | Diffraction of electromagnetic waves; hyperbolic alignment |                                                                                       |
| 2  | Palearms slope                | Oblique and sub-horizontal chaotic arrangement of the in-phase axes |                                                                                       |
| 3  | Ancient Landslide Body        | Subhorizontal and chaotic arrangement of intersecting in-phase axes, presence of diffractions |                                                                                       |