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The results of the Research of Machavariani Street Landslide by Electroprospecting and Seismic Methods

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ABSTRACT

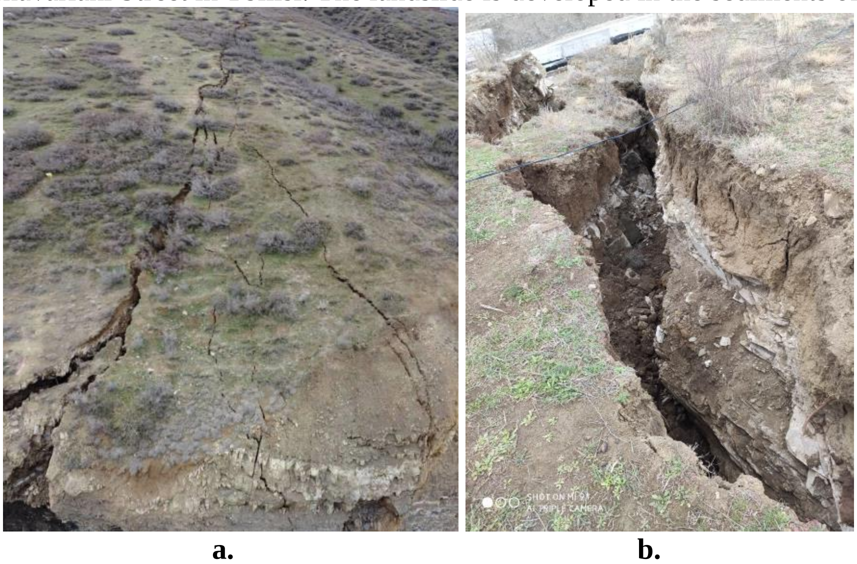
By means of geophysical methods (seismic and electromagnetic methods) it is possible to determine various characteristics of the geological environment. Seismic methods allow us to determine the elastic parameters of the environment (density, Poisson's ratio, Young's dynamic modulus, etc.), and with the help of electroprospecting methods electromagnetic characteristics of the geological environment (resistance, conductivity, etc.). From the results of the complex search, we can draw conclusions about the structure and humidity of the subsurface of the studied area. The paper presents the results of the studies conducted on the landslide that developed on Machavariani street in Tbilisi. Seismic surveys were conducted using the method of refracted waves and seismic tomography, and electrical surveys were conducted using the methods of vertical electrical sounding and natural electric field. Based on the analysis of the received results, conclusions have been made about the depths of the landslide scarps, the mechanical condition of rocks, their humidity and the possible presence of underground water flows.

Key words: *longitudinal waves, transverse waves, seismic tomography, electroprospecting, vertical electrical sounding, natural electric field*

Introduction

In today's world, the extensive development of urbanization and construction contributes to the increase of both environmental hazards and risk, as well as seismic risk. In this regard, the city Tbilisi is no exception. In terms of ecological risk and safety assessment, scientific assessment of geodynamic processes is necessary. Based on the above, it becomes clear that for the correct assessment of ecological risk and safety, geophysical studies using modern methods are of crucial importance [1,2].

The paper presents St. The results of the geophysical (electrical and seismic) survey of the landslide that developed on Machavariani Street in Tbilisi. The landslide is developed in the sediments of Oligocene age.



a. **b.**

Fig. 1. a) Machavariani landslide photographed by drone, b) one of the ruptures of Machavariani landslide

Oligocene sediments are intensively fissured and represented by alternations of clays, argillites and sandstones. Machavariani street landslide is a typical block landslide (Fig.1). The surface area of the moving landslide body is about 1.5 hectares, and the volume is 225 thousand cubic meters. Its formation is related to intensively fissured rocks.

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Complex geophysical studies (electric prospecting, seismic profiling, seismic tomography) were conducted to assess the depth structure, geometry, lithology, humidity, watering and its danger of the block landslide. The methods of electroresearch are quite powerful and experienced means for studying the geometry, lithology, humidity of landslides [1,3,5,14]. During the study of landslides, electro-research methods are always assigned an important role. Geophysical methods are indispensable for determining the depth structure of the landslide, the elastic parameters of the underground rocks, the depths of the cracks on the landslide [7,11,13].

Electroprospecting works. On March 29, 2021, on the landslide located on Machavariani street (Tbilisi, Georgia), electroprospecting works were carried out using the method of vertical electrical sounding.

Fig. 2. Positioning points of vertical electrical sounding in landslide body area.

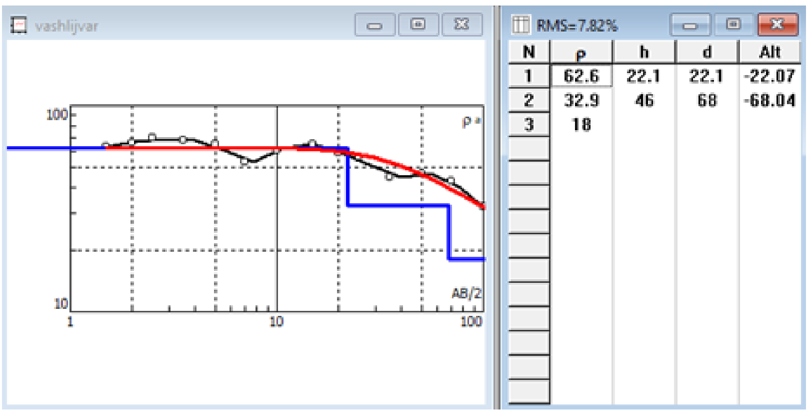

Fig. 3. Vertical electrical sounding curve obtained as a result of measurements near the landslide toe.

The first measurement was made near the landslide tongue, on Machavariani Street (Fig. 2). The measurement was performed by the vertical electrical sounding method. The maximum extension of the current electrodes was 100 meters. The corresponding vertical electrical sensing (VEZ) curve is presented in Fig. at 3. The figure shows the curve obtained as a result of resistance measurements in black, the theoretical curve in red, and the layers separated by inversion in blue. The analysis of the VES curve allows us to assume that the clay layer starts from a depth of about 25-30 meters. This result is in some agreement with the results obtained by coring wells in the vicinity of vertical electrical sounding points.

The second measurement was made on the landslide body, about 500 meters away from the first point (Fig. 4). The measurement was also performed using the vertical electrical sensing method. The maximum extension of the current electrodes was 250 meters.

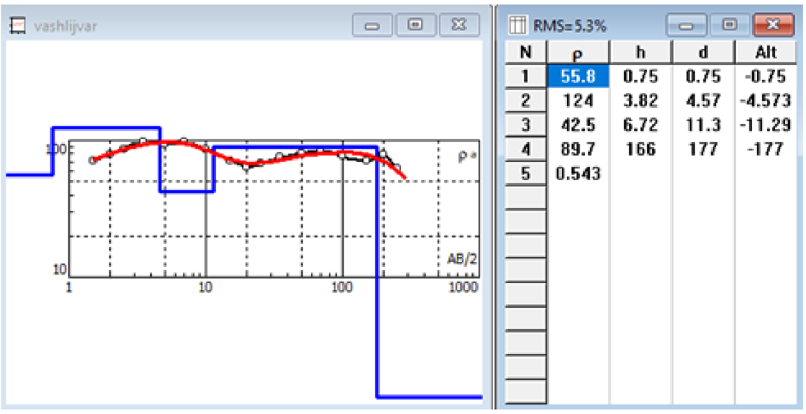

Fig. 4. Vertical electrical sounding curve obtained as a result of measurements on a landslide body.

The corresponding vertical electrical sounding curve is presented in Fig. 4. Potentially humidity layers are separated on the VES. However, the analysis of the vertical electrical sensing curve allows us to assume that the entire investigated subsurface is characterized by high humidity, which may indicate the inflow of water from certain areas.

Works of natural electric field measurement. The natural electric field was measured in the vicinity of the vertical electric sounding point (Vashlichvari2, Fig. 2). The measurement was carried out by the potential method. One electrode was fixed at the center of a stationary circle, and the other electrode, connected to it by a 25-meter cable, moved around the circle by at an 90 degrees step. The potential difference was measured at each step [6]. Measurements of the natural electric field allow determining the possible presence and direction of groundwater flow. Based on the asymmetry of the diagram, it can be assumed that there is movement of underground water. By analyzing the presented diagram (Fig. 5), we can assume the direction of groundwater flow [6].

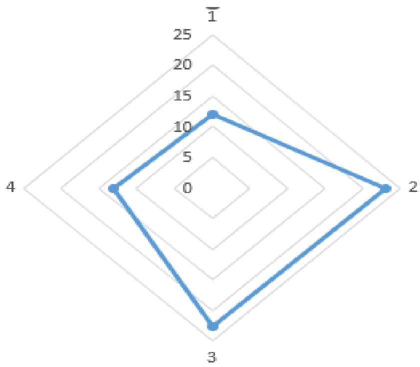

Fig. 5. Natural field measurement result with circular (90° angle) rotation.

Seismic profiling and seismic tomography. In order to investigate the state of the landslide developed in the vicinity of Machavariani Street, 4 seismic profiles of different lengths were conducted using the method of refracted waves and seismic tomography [8,9,10]. Figure 6 shows the scheme of the profiles, and also Table 1 gives the corresponding coordinates. Profile N 1 is oriented along the fault and crosses it, and profiles N 2 and N 3 - parallel to the fault. However, profile N 3 also crosses the fault. Profile N 4 is also directed in the direction of the rupture. Profiles N 2 are conducted in the upper, relatively stable zone of the landslide area, and profile N 3 - directly on the body of the landslide. Additionally, both longitudinal and transverse wave velocities were determined for all profiles, and corresponding physical-mechanical parameters were estimated for each layer.

The following physical-mechanical parameters were determined:

1	**Vp m/sec**	Longitudinal wave velocity
2	**Vs m/sec**	Shear wave velocity
3	**Vs/Vp**	Velocitys ratios
4	**ρ gr/cm^3**	density
5	**μ**	Poisson's ratio
6	**Ed Mpa**	Young's Dynamic modulus
7	**Gd MPa**	Dynamic shear modulus
8	**KdMpa**	Dynamic bulk modulus
9	**D Mpa**	General deformation modulus
10	**τ Mpa**	Hardness limit by compression

Note. 1-3 of the mentioned parameters are obtained as a result of research, 5-8 are calculated based on known theoretical assumptions, and 4, 9, 10 are obtained using empirical connections available to us.

After obtaining accurate geological information, it will be possible to determine the identification of separated layers and determine the relevant physical-mechanical parameters with greater accuracy [8,9,10,12].

Fig.6. Layout scheme of seismic profiles. N s indicates the beginning of the profile, and N e - the end of the profile.

Seismic slice N 1 is particularly informative, showing that in the southwestern part a lenticular depression of the third layer is observed, which should lead to a relatively stable condition, but since nearby, the exposure in the area adjacent to this street shows a newly observed fault with a displacement of up to 0.5 meters, obviously that this area is also experiencing active deformations.

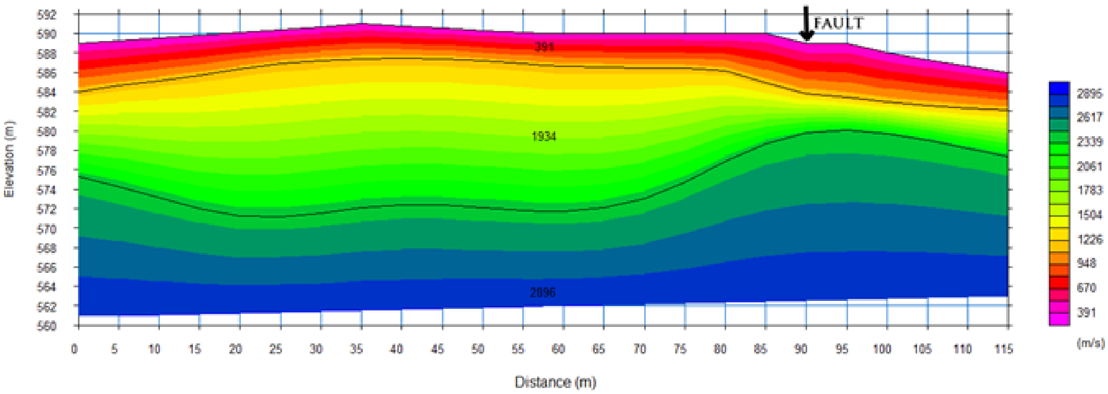

Fig. 7. Seismic cross section N 1.

In its northeastern part, to the right of the fault, (right of the fault indicated in Fig. 6) there is a slope of the existing layers, which is one of the main factors for the development of the landslide event. Based on the above, in order to obtain more complete information, we consider it expedient to cover the entire area of landslide occurrences and its adjacent zones with a network of complex geophysical surveys.

Table 1. Values of physical-mechanical parameters for profile N 1.

Layer N	Parameters	Parameter description	values
1	**Vp m/sec**	Longitudinal wave velocity	391
	Vs m/sec	Shear wave velocity	268
	Vs/Vp	Velocitys ratios	0.69
	ρ gr/cm^3	Density	1.43
	μ	Poisson's ratio	0.06
	Ed Mpa	Young's Dynamic modulus	220
	Gd MPa	Dynamic shear modulus	103
	KdMpa	Dynamic bulk modulus	817.82
	D Mpa	General deformation modulus	3.30
	τ Mpa	Hardness limit by compression	-
2	**Vp m/sec**	Longitudinal wave velocity	1934
	Vs m/sec	Shear wave velocity	1189
	Vs/Vp	Velocitys ratios	0.61
	ρ gr/cm^3	Density	2.14
	μ	Poisson's ratio	0.20
	Ed Mpa	Young's Dynamic modulus	7220
	Gd MPa	Dynamic shear modulus	3019
	KdMpa	Dynamic bulk modulus	39619.25
	D Mpa	General deformation modulus	793.89
	τ Mpa	Hardness limit by compression	4.95
3	**Vp m/sec**	Longitudinal wave velocity	2896

	Vs m/sec	Shear wave velocity	1236
	Vs/Vp	Velocitys ratios	0.43
	ρ gr/cm^3	density	2.36

μ	Poisson's ratio	0.39
Ed Mpa	Young's Dynamic modulus	10020
Gd MPa	Dynamic shear modulus	3609
KdMpa	Dynamic bulk modulus	149993.20
D Mpa	General deformation modulus	1328.50
τ Mpa	Hardness limit by compression	5.92

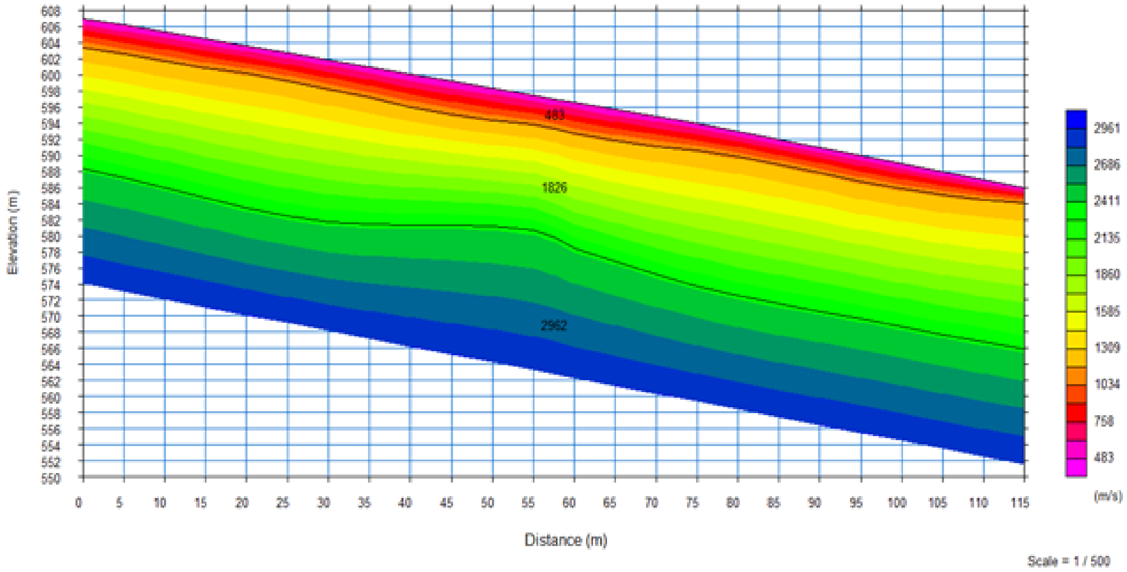

Fig. 8. Seismic cross section N 2.

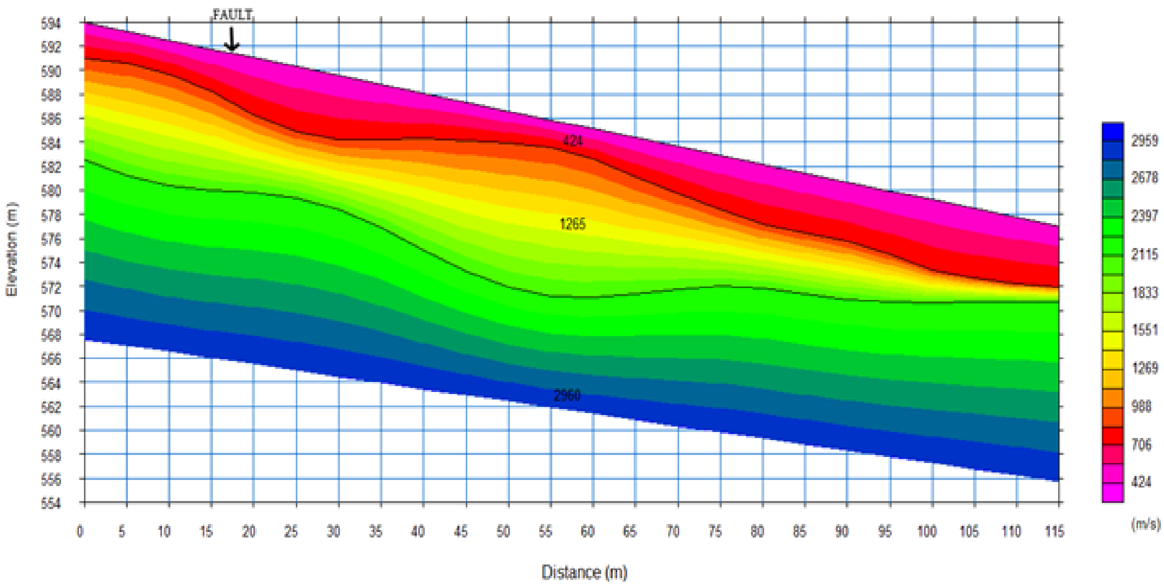

Fig. 9. Seismic cross section N 3.

Table 2. Values of physical-mechanical parameters for profile N 2.

Layer N	Parameters	Parameter description	values
1	**Vp m/sec**	Longitudinal wave velocity	483
	Vs m/sec	Shear wave velocity	339
	Vs/Vp	Velocitys ratios	0.70
	ρ gr/cm^3	Density	1.51
	μ	Poisson's ratio	0.01
	Ed Mpa	Young's Dynamic modulus	350
	Gd MPa	Dynamic shear modulus	173
	KdMpa	Dynamic bulk modulus	1208.55
	D Mpa	General deformation modulus	6.83
	τ Mpa	Hardness limit by compression	-
2	**Vp m/sec**	Longitudinal wave velocity	1826
	Vs m/sec	Shear wave velocity	1103
	Vs/Vp	Velocitys ratios	0.60
	ρ gr/cm^3	Density	2.10
	μ	Poisson's ratio	0.21
	Ed Mpa	Young's Dynamic modulus	6210
	Gd MPa	Dynamic shear modulus	2561
	KdMpa	Dynamic bulk modulus	36038.60
	D Mpa	General deformation modulus	626.54
	τ Mpa	Hardness limit by compression	4.20
3	**Vp m/sec**	Longitudinal wave velocity	2962
	Vs m/sec	Shear wave velocity	1234
	Vs/Vp	Velocitys ratios	0.42
	ρ gr/cm^3	Density	2.38
	μ	Poisson's ratio	0.39
	Ed Mpa	Young's Dynamic modulus	10090
	Gd MPa	Dynamic shear modulus	3617
	KdMpa	Dynamic bulk modulus	160181.33
	D Mpa	General deformation modulus	1343.11
	τ Mpa	Hardness limit by compression	5.93

Table 3. Values of physical-mechanical parameters for profile N 4.

Layer N	Parameters	Parameter description	values
1	**Vp m/sec**	Longitudinal wave velocity	268
	Vs m/sec	Shear wave velocity	188
	Vs/Vp	Velocitys ratios	0.70
	ρ gr/cm^3	Density	1.30
	μ	Poisson's ratio	0.02
	Ed Mpa	Young's Dynamic modulus	90

	Gd MPa	Dynamic shear modulus	46
	KdMpa	Dynamic bulk modulus	321.78
	D Mpa	General deformation modulus	0.81
	τ Mpa	Hardness limit by compression	-
2	**Vp m/sec**	Longitudinal wave velocity	1035
	Vs m/sec	Shear wave velocity	630
	Vs/Vp	Velocitys ratios	0.61
	ρ gr/cm^3	Density	1.83
	μ	Poisson's ratio	0.21
	Ed Mpa	Young's Dynamic modulus	1750
	Gd MPa	Dynamic shear modulus	725
	KdMpa	Dynamic bulk modulus	9899.43
	D Mpa	General deformation modulus	85.67
	τ Mpa	Hardness limit by compression	1.19
3	**Vp m/sec**	Longitudinal wave velocity	2433
	Vs m/sec	Shear wave velocity	1023
	Vs/Vp	Velocitys ratios	0.42
	ρ gr/cm^3	Density	2.26
	μ	Poisson's ratio	0.39
	Ed Mpa	Young's Dynamic modulus	6590
	Gd MPa	Dynamic shear modulus	2367
	KdMpa	Dynamic bulk modulus	102311.68
	D Mpa	General deformation modulus	687.81
	τ Mpa	Hardness limit by compression	3.88

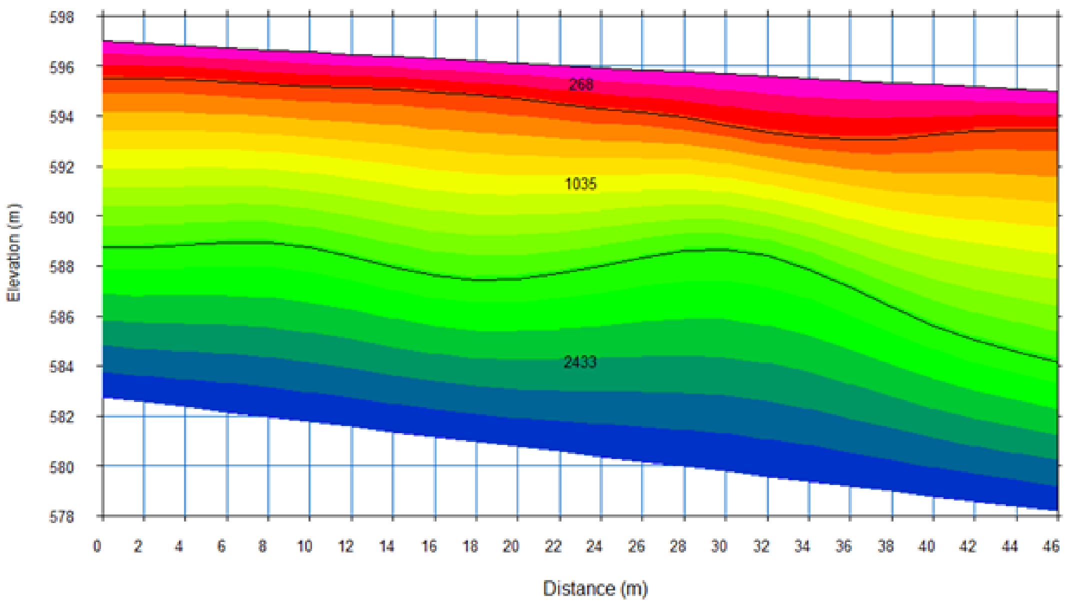

Fig. 10. Seismic cross section N 4.

Along with this, an experimental investigation of its depth was conducted in the area of the rupture. Based on the mathematical analysis of the received seismograms, it was determined that the depth of the open part of the fault is about 16 m. At the same time, the possible continuation of the opened part in depth is not excluded.

Conclusion:

1.The surface area of the moving landslide body is about 1.5 hectares, and the volume is about 225 thousand cubic meters.
2.The main rupture plane in the Main scarp of the landslide body is approximately 14-16 m deep;
3.The amount of horizontal displacement of the block landslide is about 2.30-2.40 m;
4.The analysis of the vertical electrical sounding curve allows us to assume that the clay layer begins at a depth of about 25-30 meters. This result is in quite good agreement with the results obtained by coring wells in the vicinity of VES.
5.Potentially humidity layers are separated on the presented vertical electrical sounding curve. In addition to the watered layers, the analysis of the vertical electrical sounding curve allows us to assume that the entire investigated underground space is characterized by high humidity, which may indicate the inflow of water from certain areas in the landslide body. Additional studies are needed to achieve high reliability of the results.
6. It is advisable to organize monitoring of unstable sections with different geological and geophysical methods in order to determine the speed of different sections of the landslide.
7. On the most moving block, it is advisable to install the patented, telemetric automatic multi-sensor early warning system created at the Institute of Geophysics (4). We consider installation of the system a must, because in the case of seasonally increased rainfall, activation of landslides is not excluded;
8. It is necessary to determine the underground water supply, for which it is necessary to continue the research using the natural electric field method and also conduct isotope analysis of the water moving in the landslide body.
9. It is necessary to avoid the landslide body as much as possible from the inflow of underground and surface waters, for which it is necessary to make an appropriate engineering decision (it may be a drainage arrangement). In order to effectively solve this task, it is necessary to determine the geometry of the groundwater feeding the landslide body. And, in order to determine the geometry of underground waters, it is necessary to conduct complex geophysical studies.

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მაჭავარიანის ქუჩის მეწყრის ელექტროსაძიებო და სეისმური მეთოდებით კვლევის შედეგები

ნ. ვარამაშვილი, მ. გიგიბერია, ჯ. ქირია, ნ. ღლონტი

რეზიუმე

გეოფიზიკური მეთოდების (სეისმური და ელექტრომაგნიტური) საშუალებით შესაძლებელია გეოლოგიური გარემოს სხვადასხვა მახასიათებლების დადგენა. სეისმური მეთოდები საშუალებას გვაძლევს დავადგინოთ გარემოს დრეკადი პარამეტრები (სიმკვრივე, პუასონის კოეფიციენტი, იუნგის დინამიური მოდული და ა.შ...), ხოლო ელექტროძიების მეთოდების საშუალებით შესაძლებელია გეოლოგიური გარემოს ელექტრომაგნიტური მახასიათებლების (წინააღმდეგობა, გამტარობა და ა.შ.) დადგენა. კომპლექსური ძიების შედეგებიდან შეიძლება გავაკეთოთ დასკვნები შესწავლილი ტერიტორიის აგებულების და დატენიანების შესახებ. ნაშრომში წარმოდგენილია ქ. თბილისში, მაჭავარიანის ქუჩაზე განვითარებულ მეწყერზე ჩატარებული კვლევების შედეგები. სეისმური კვლევები ჩატარდა გარდატეხილი ტალღების და სეისმური ტომოგრაფიის მეთოდით, ხოლო ელექტრული კვლევები - ვერტიკალური ელექტრული ზონდირების და ბუნებრივი ელექტრული ველის მეთოდებით. მიღებული შედეგების ანალიზის საფუძველზე, გაკეთებულია დასკვნები ქანების ბზარების სიღრმეების, ქანების მექანიკური მდგომარეობის, მათი გაწყლიანების და ასევე მიწისქვეშა წყლების ნაკადების შესაძლო არსებობის შესახებ.

საკვანძო სიტყვები: გრძივი ტალღები, განივი ტალღები, სეისმური ტომოგრაფია, ელექტროძიება, ვერტიკალური ელექტრული ზონდირება, ბუნებრივი ელექტრული ველი.

Результаты исследования оползня на улице Мачавариани методами электроразведки и сейсморазведки

Н.Д. Варамашвили, М.Г. Гигиберия, Дж.К. Кирия, Н.Я. Глонти

Резюме

С помощью геофизических методов (сейсмических и электромагнитных) можно определять различные характеристики геологической среды. Сейсмические методы позволяют определить упругие параметры среды (плотность, коэффициент Пуассона, динамический модуль Юнга и др.), а с помощью электроразведочных методов электромагнитные характеристики геологической среды (сопротивление, электропроводность и др.). По результатам комплексного поиска можно сделать выводы о структуре и влажности недр изучаемой территории. В статье представлены результаты исследований оползня, образовавшегося на улице Мачавариани в Тбилиси. Сейсморазведочные работы проводились методом преломленных волн и сейсмотомографии, а электроразведка – методами вертикального электрического зондирования и естественного электрического поля. На основании анализа полученных результатов сделаны выводы о глубинах залегания оползневых уступов, механическом состоянии горных пород, их влажности и возможном наличии потоков подземных вод.

Ключевые слова: продольные волны, поперечные волны, сейсмическая томография, электроразведка, вертикальное электрическое зондирование, естественное электрическое поле.