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GEOPHYSICAL AND ENGINEERING METHODS IN THE STUDY OF THE UKRAINIAN PIPELINE SYSTEMS

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ЗАСТОСУВАННЯ ГЕОФІЗИЧНИХ МЕТОДІВ ПРИ ІНЖЕНЕРНИХ ДОСЛІДЖЕННЯХ ТРАС ТРУБОПРОВІДНИХ ТРАНСПОРТНИХ СИСТЕМ УКРАЇНИ

Purpose. Review and analysis of the most informative and advanced geophysical methods for studying natural and anthropogenic processes that affect the design and safe operation of pipeline transportation systems of Ukraine.

Methodology. It is suggested to use a complex of geophysical studies for engineering surveys while designing and operating linear underground structures of Ukrainian pipelines**.** The use of conventional electrical methods of in conjunction with a new method of resonant acoustic profiling significantly increases informative value of the research.

Findings. The analysis of traditional electrometric and new resonant acoustic geophysical methods of research is performed. There is shown a possibility of selecting the best sites for the construction and operation of pipeline transport systems. The effectiveness of integrated application of geophysical methods for substantiating protection measures of pipeline transportation systems from the impact of natural and anthropogenic processes is disclosed.

Originality. For the first time it is demonstrated how to use the new geophysical method of resonant acoustic profiling in conjunction with a set of conventional electrical methods on such complex and demanding engineering structures as the pipeline transport system of Ukraine.

Practical value. Using the method of resonant acoustic profiling to study the geological section, mapping of landslide areas, collapses, water cut areas, allocation of aquifers and zones of tectonic disturbances, detection of karst zones, and for examining the possible sites of leaks of liquid or gaseous filler through damage in pipelines. Identification of possible areas of corrosion on the pipeline transport systems with electrical methods – VES (vertical electric sounding), "Remote electrode", measurement of potential gradient and SEP (symmetrical electrical profiling).

Keywords: *pipeline transportation systems, engineering survey, VES, SEP, "Remote electrode" method, measurement of potential gradient*

Introduction. A specific problem of both underground and terrestrial geological space of Ukraine is a pipeline transport. The length of the main pipelines in Ukraine is over 43.000 km, of which: the main gas pipelines makes 35.000 km, the main oil pipelines – 4.000 km, product pipelines – 3.300 km. The number of accidents at the enterprises of the industry annually reaches 1.500 (for example, out of 35.301 km of the main operated gas pipelines, 21.1 % or 7.500 km has fully served its amortization period, or has short-lived anti-corrosion coating) [1]. The occurrence of serious accidents on the pipelines (oil emissions petroleum products and other substances, gas explosions etc.) may result in emergency with fatal casualties, also it may cause economic and ecological destabilization of entire regions of the country. Failure of the transit network of the main pipelines, that transport oil and gas to Western Europe, can lead to large economic losses.

Ensuring the safe operation of pipeline transport is an integrated complex task, which contains a solution of technical, technological, economic and organizational aspects.

Presentation of the main research. In general, while designing and operating pipeline transport systems, for the development of design and working documentation for the overhaul or construction of the facility, as well as for making informed design decisions, the purpose of engineering survey is a comprehensive study of natural and man-made conditions of pipeline transportation systems trails. As for the problems that are solved in the assessment of their impact, they can be described as follows:

1) studies of lithologic-genetic and structural-geological features;

2) determining a set of physical and physical-mechanical indexes of rock massif properties, and assessment of their role in the formation of the character of manifestations of rock pressure and rock displacement;

3) assessment of natural and reduced stress fields in complex constructed strata;

4) comprehensive assessment of structural-phase processes of rock massifs in the form of fields and identification of their deformation mechanisms.

The complex of engineering survey can be divided into the following areas: study of trails for pipelines construction; search of pipelines and determination of their position; pipelines condition assessment; occurrence of pipeline corrosion sections; study of possible sites of leakage in case of pipeline damage.

Pipeline transportation systems are the capital engineering structures designed for long service life, designed for the transportation of natural or artificial gaseous or liquid substances, powdered and liquefied masses, as well as solid fuel and other solids in a form solution under the influence of a pressure difference in pipe cross-sections.

Depending on the transported environment, pipeline transportation systems are divided into ammonia pipelines, water pipelines, gas pipelines, oil pipelines and petroleum product pipelines.

Linear engineering facilities feature carrying a large volume of excavation, which entails a substantial change in the composition and properties of rocks. Primarily, it is associated with the formation in the trench of not dense soil of backfill, which is distinguished by uneven density and enhanced filtration capacity. Most of the main pipelines are laid in clay soils; as it is well known for clay soils the movement of water through pores is possible not only under the influence of mechanical forces, imposed by the hydrostatic pressure gradient, but also under the influence of other physical, chemical and physical-chemical forces: 1) with a gradient of the field of direct current (electroosmosis); 2) having dissolved electrolyte concentration gradient (capillary osmosis) available; 3) with a temperature gradient (thermal osmosis). The mechanism of water movement during electroosmosis, osmosis and thermal osmosis is the same – it is a movement of the liquid on the surface of particles, unlike filtration, when there is a movement of free water on the layer of bound water. This indicates that for different operating conditions there may be changes in negative / positive potential (cathode / anode) depending on the physical and chemical heterogeneity of both the environment (soil) and metal of pipeline, that is, there is an alternating zone, and it is known to significantly affect the service life of pipelines.

Processes of pipeline corrosion in underground conditions are caused by a large number of physical and physical-mechanical factors that determine its intensity. The soil as the environment in which the corrosion process occurs is characterized by a variety of interrelated and time varying parameters. The complex interrelationship of these parameters leads to the fact that one or another parameter in various combinations can operate not only at different intensities, but also can change the direction of impact. Corrosion aggressiveness of soil depends on the structural and textural characteristics, the shape of the ground particles packaging, total porosity, occurrence, shape and distribution of conductive inclusions.

It is established that the territory of a regional spread of corrosion damage on the natural features complex is characterized by a complicated engineering-geological conditions. This is reflected in a different slope and uneven topography dissection, complex geological structure and the difference of composition and properties of rocks of pipe laying areas with adjacent sections. In areas with fairly widespread corrosion processes, especially in the areas of parallel constructing of several pipelines threads, there are difficulties in carrying out detailed investigations to establish the patterns of influence of soil environment on the occurrence of corrosion processes, as well as the further formation and development of the areas of corrosion damage.

Cropping steep slopes combined with the destruction of vegetation within the band of laying pipeline transportation systems provokes the activation of landslides, avalanches, talus and the development of unstable alluvial formations, and also leads to a change in groundwater levels. Due to destruction of vegetation and changes in the morphology of the relief, change of soil moisture, composing the around-pipeline environment has a significant impact both on the kinetics of corrosion processes and the secondary processes directly in the "land-pipe" contact zone. This occurs in the change of the ambient temperature and, therefore, the temperature of pipeline surface, changing the pH value (pH), the electrical conductivity of the soil, content of gases and, consequently, contributes to creating conditions for the life of the various bacteria, which can dwell in different conditions in the process of symbiosis. The most dramatic changes in the geological environment occur at the initial stage of operation of facilities. In the future, the relationship between buildings and the environment are gradually stabilized, although the environment changed during the operation of the object is not completely restored.

Among exogenous geological processes within the pipeline transportation system trails, the most widespread are: weathering, gravitational processes, talus, avalanches, landslides, erosion and flooding.

Weathering can be frosty, biological and chemical in the bedrock output locations at the surface. Landslide areas are confined to the valleys of rivers and streams, to the sloping areas, and are also widely developed in terrigenous flysch of Cretaceous-Paleogene and diluvium covering them.

From the standpoint of geophysical studies, with electrochemical protection of underground pipelines a number of measurements are performed, in particular, those of the potential difference of "pipe-to-ground", polarization potential in the pipeline, value of soil corrosion activity, and condition of insulation coating. These measurements make it possible to solve a number of tasks, namely, the definition of security of pipelines (ECP effectiveness), localization of defects, integrated assessment of the condition of the insulation coating (the magnitude of the current decay in the pipe), definition of areas of high and increased corrosion hazard, and to assess the remaining service life of the pipe based on metal-aging effect.

A technique of revealing corrosive gas pipelines, corrosion activity of soil and site selection for the anode grounding provides:

- reconnaissance of pipelines and technological facilities in the area with markings and GPS referenced measurement points;
- measurement of "pipe-to-ground" capabilities of underground pipelines on the measurement points (MP), valves and other accessible locations to determine the status of cathodic polarization protection;
- measurement of the longitudinal "pipe-to-ground" potential to determine the cathodic polarization security along the length of the pipeline and the transverse electric field gradient with a 5 m step to determine the quality of the insulation of covering communications;
- assessment of the overall condition of the insulation coating by measuring the magnitude of the alternating current flowing in the pipe by a contactless method;
- assessment of the impact of stray currents on the corrosion condition of the insulation coating and pipes;
- measurement of technological pipeline occurrence depth;
- measurement of the electrical resistivity of soils by symmetrical electrical profiling;
- implementation of vertical electrical sounding of the ground to a depth of 100 m in order to choose the site for the anode grounding.

Methods of vertical electrical sounding (VES) involve measurement of the resistivity by machine, in which the distance between the current electrodes increases continuously from one measurement to another. The final result of sounding is the sensing curve of apparent resistivity (ρ) of the supply line spacing.

Sounding is performed by several measuring lines, whose size varies depending on the distance between the current electrodes. With technically feasible values of the current in the chain of supplying electrodes, this allows providing a sufficiently wide opportunity for confident measurements of the potential difference in the measuring line. In the transition from one measuring line to another, measurement ρ is performed at two adjacent values of spacing MN. The sequence of measuring spacing of supply and measuring lines is usually chosen as standard and is set by the current instruction on the implementation of electric survey.

From the measured values of ρ the VES diagram is constructed directly in a field, reflecting the dependence of ρ from the value of ½ of the supply line spacing. This diagram is constructed in a double-logarithmic scale with modulus equal to 6.25 cm. Sections of the curve obtained by different measurement lines are displayed on the diagram in the form of individual sections. Gaps between the sections are explained by changes in the distance between the power electrodes and the measuring line, i. e. the change of measurement depth, or the influence of local inhomogeneities in the vicinity the measuring electrodes. If between the ends of sections of VES curve is greater than 10 %, it is recommended to shift slightly the center and repeat the measurement probe.

Vertical electric sounding was performed off-site "Vinnitsa-2" filling station. During the operation there the device "Electrotest-S" was used, in an alternating current mode with a frequency of 5 Hz, symmetrical installing with bronze measuring electrodes MN and steel feeding electrodes AB.

Quantitative interpretation of VES was performed using "IPI2Win" software. According to the control measurements the accuracy of the depth horizons and apparent resistivity must be ±5 % (Fig. 1).

Interpretation of the data reveals the following lithological layers. The first layer (capacity (h) is 0.75 m and electrical resistivity (ρ) is 143 Om ∗ m) is represented by sandy loams with impurities of organic substances. The second layer (*h* is 16 m and ρ is 32 Om ∗ m) is represented by loam and clay. The third layer (ρ is 212 Om ∗ m) is represented by fractured limestones. The most promising layer for the site under the anode grounding involves clays and loams, since they are characterized by the lowest apparent electrical resistance.

To determine the quality of the insulation coating and corrosion activity of soil, the measurements of transverse gradient of technological pipelines protective potential are carried out, in increments of 5 m along the pipe axis (setting $MN = 5$ m). Also, "Remote electrode" method is applied (one of the electrodes is located outside the territory of the site with a view to avoid the influence of electric fields of adjacent technological pipelines and anode zones, created by groundings of cathodic protection installation. In locations of abnormal gradient values (when the magnitude of the gradient values increased by 2–3 times) the detailed measurements are carried out (measuring step was reduced to 1–2 m).

Corrosion activity of soil at the site is determined by the measurement data of the electrical resistance of soil basically by "F-4103-M1" device, with symmetrical Wenner array at two electrode spacing of 3 and 2 m.

Location of technological pipelines is determined by a "Sprut-5m" locator using a frequency generator. Also,

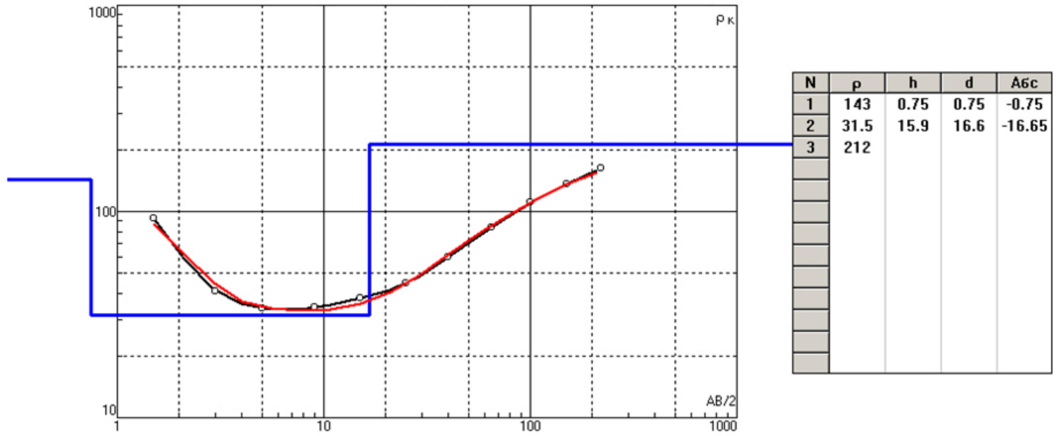

Fig. 1. Quantitative interpretation of VES curve

the depth of technological pipelines is measured using a step up to 50 m, and in their rotation places [2].

Based on the results of these studies potential and electrical resistivity diagrams are constructed:

1. Diagram of "pipe-to-ground" potential distribution. The main criterion for protection of technological pipelines from soil corrosion is the value of the protective potential of the "pipe-to-ground" regarding the copper-sulphate comparison electrode ($Cu/SuSO_4$):

- minus 900 mV with a resistive component;
- minus 850 mV for the polarization potential.

During the examination of the supply gas pipeline of CNG stations "Vinnitsa-2" the values of a "pipe-to-ground" potential are is in the limits of standard, which indicates the lack of cathodic protection of the gas pipeline (Fig. 2).

2. Diagram of "ground-to-ground" transverse gradient potential. Condition of the insulating coating of technological pipelines is determined by the magnitude of transverse gradient values.

Condition of the insulating coating of the supply gas pipeline of CNG station "Vinnitsa-2" according to the schedule of transverse gradient potential "ground-to-ground" is in a satisfactory condition (Fig. 3).

3. Diagram of the electrical resistance (determination of soil corrosion activity). Corrosion activity of soil is determined according to the measurement of the electrical resistance of soil by "F-4103-M1" device with symmetrical Wenner Array. Corrosion activity of soil to the metal of technological pipelines is determined in accordance with the requirements of NSU 4219-2003. The main parameter in this case is the value of the electrical resistance of the soil. According to this parameter soils are divided:

- less than 20 Om ∗ m – soils with low corrosion activity;
- from 20 Om ∗ m to 50 Om ∗ m – soils with medium corrosion activity;
- over 50 Om ∗ m – soils with low corrosion activity [3].

The supply gas pipeline of CNG station "Vinnitsa-2" is located in soils with low (> 50 Om ∗ m) and medium corrosion activity (Fig. 4).

The method of resonant acoustic profiling (RAP) relates to geophysical methods, which study and use natural physical fields to obtain information. This puts it in the category of low-cost methods, because it eliminates the need for the use of cumbersome excitation sources. To obtain information the method uses Earth's own acoustic field, namely, the acoustic resonance field, occurring in the rock strata under the influence of various external factors. External factors include sources of Earth's crust seismic activity, mechanical vibrations, resulting from the earth's strata stress, movement of the planets, and much more. Under the influence of external factors in the strata of rocks fluctuations occur,

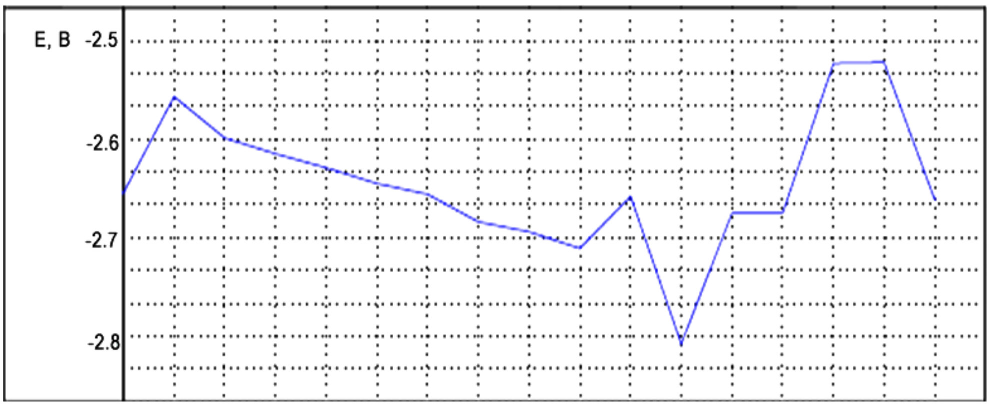

Fig. 2. Diagram of "pipe-to-ground" potential distribution

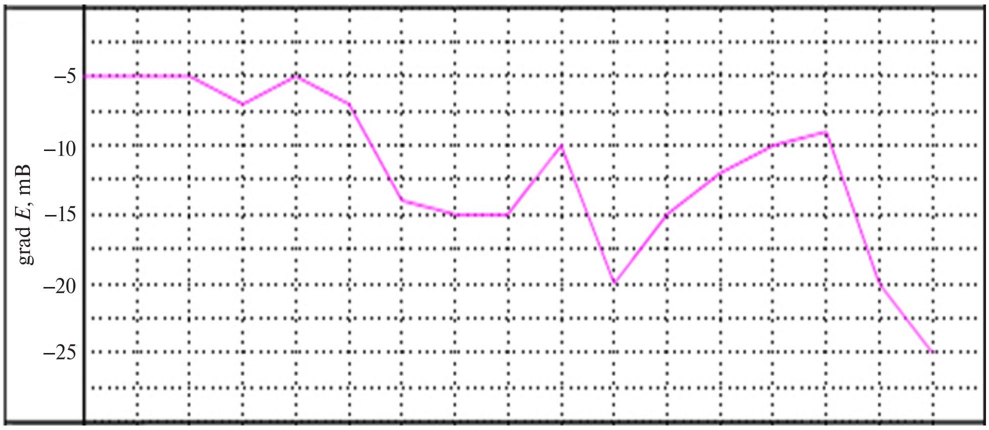

Fig. 3. Diagram of "ground-ground" transverse gradient potential

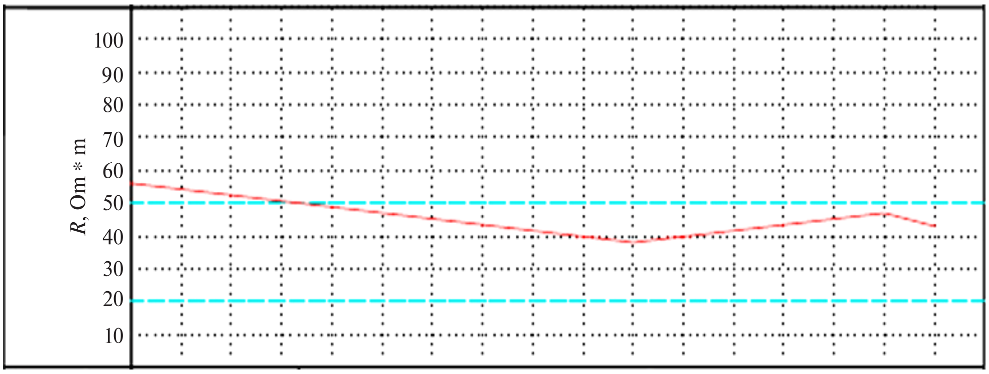

Fig. 4. Diagram of electrical resistivity

whose frequency is inversely proportional to the power of the oscillating "layer". The resulting elastic vibrations are generated by transverse waves, thus the clarity of manifestation of the boundaries between resonator layers is determined by a possibility of mutual "slippage" of adjacent layers if a shear elastic process occurs in the test array, i.e. due to the degree of "weakening" of contact between the strata of rocks located between the observation surface and the surface of "weakened mechanical contact" (WMC). These surfaces may be caused by the following factors:

- abrupt change of lithotypes of rocks of the studied section;
- interlayers of various origins (carbonaceous, clay, mica, etc.);
- interruptions in sedimentation;
- extrusion and intrusive contacts;
- tectonic disturbances;
- borders of section "sedimentary mantle – crystalline basement" and "loose sediments – sedimentary mantle".

In general, the weaker the contact is, the greater the possibility of a mutual "slippage" of adjacent layers is, and, therefore, the greater the amplitude of natural oscillations arising is.

For mechanical excitation of subsurface formation and strengthening of natural oscillation amplitude, one can use any simple source of excitation and the excitation source power does not matter.

Ideally, the RAP signal is a decaying polyharmonic sinusoid, which is the sum of the natural acoustic vibrations of rock strata [4].

The technique consists in observing the acoustic signal measurements at the observation point from the sensor movement (acoustoelectric transducer) on the profile, and specification of information received depends on the density of the observation network. Since one operator can carry works in most cases and there is no need to use cumbersome excitation sources, measurements can be performed almost anywhere [5].

In studying the trails for the construction of pipeline transportation systems, this method solves the following problems:

- study of the geological section;
- mapping of landslide areas, collapses, water cut;
- mapping of aquifers;
- mapping of the zones of tectonic disturbances.

Apart from these problems, karst-suffusion processes development is to be mentioned as an example of the study results. Karst phenomena are fairly widespread; however, depending on the geology of the region, they may be manifested in different ways. Surface Karst, growing in the Cretaceous (chalk and marl) occurs widely. Surface and ground water penetrating through thick sand and sandy loam with loam on the surface of the Cretaceous deposits, soften them, which may not be apparent on the surface. However, the bearing capacity of soil in such areas significantly decreases. Since the zones of surface karst are also the zones of significant reduction in the mechanical properties of rocks, this allows identifying them by the given method without any complications.

The RAP method can be effectively used in the investigation of the possible leak sites of liquid or gaseous filler through damage in pipelines as well as in routing pipelines and defining their location (Fig. 5).

Moreover, the RAP method can be successfully used to study the geological section during engineering works. Technical Assignment of construction work provides laying engineering communications by underground development [6]. As shown in Fig. 6, the task was successfully accomplished using the RAP method. As a result of this work, apart from the roof (12 m depth) and bottom (26 m depth) of the project layer, whose power is maintained throughout the length of the profile, all the layers of the studied section are marked with great specification. The results of the work coincide with the data of sections, obtained during the drilling of an exploration well (Fig. 6 – to the right of the RAP section).

Conclusions. The techniques discussed in this article are optimal for the determination of natural and anthropogenic processes that affect the pipeline transportation. To search for corrosion of pipeline sections, measurements of the polarization potential are carried out. The main criterion for protection of technological pipelines from soil corrosion is the "pipe-to-ground" potential distribution. The symmetric electric resistance method allows one to determine soil corrosion activity. Using the method of vertical electrical sounding, resistivity section is built for the purpose of site selection for the anode grounding. The resonant acoustic profiling method is used to study geological sections, to map landslide areas, collapses and flooding, to allocate aquifers and tectonic disturbances zones, as well as to detect karst areas and investigate areas of possible leaks of liquid or gas fillers through damage in pipelines. Discussed methods taken together can be used to solve the above-described problems, and can also add to engineering surveys, and can be applied while assessing natural and man-made environmental conditions, creating a variety of static and dynamic models of the status and development of the geological environment and other tasks in order to support projects of construction and operation of facilities.

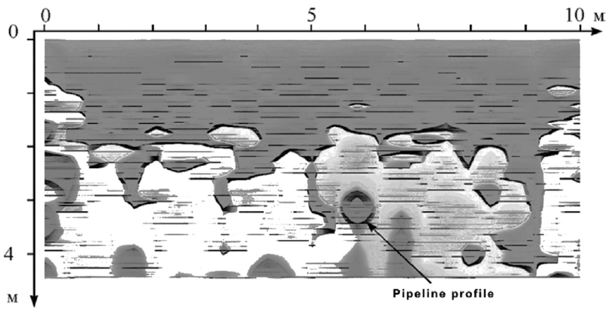

Fig. 5. Research results of RAP method for routing a pipeline

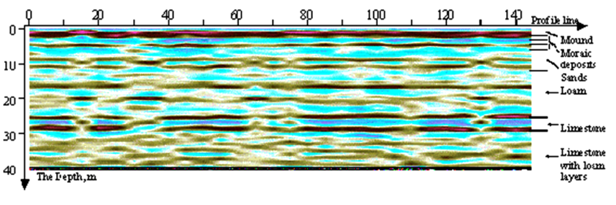

Fig. 6. The study of the geological section for constructing engineering structures

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Зуйков И. В. Применение метода резонансно-акустического профилирования (РАП) для картирования геологического разреза в районе прокладки туннеля метрополитена в г. Киеве между станциями „Иподром" – „Теремки" / И. В. Зуйков, А. В. Данилов; Журнал геоінформатика. – 2012 . – №1(141). – С. 54–62.

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Зуйков И. В. Применение метода резонансно-акустического профилирования для изучения оползневых процессов / И. В. Зуйков; Материалы II Всероссийской научно-практической конференции, посвященной столетию ПГСГА – Самара, 2011. – С. 201–207.

Мета. Розгляд та аналіз найбільш інформативних і перспективних геофізичних методів дослідження природних і техногенних процесів, що впливають на проектування та безпечну експлуатацію трубопровідних транспортних систем України.

Методика. Запропоноване використання комплексу геофізичних досліджень для інженерних вишукувань при проектуванні та експлуатації лінійних підземних споруд трубопровідного транспорту України. Використання традиційних методів електрометрії спільно з новим методом резонансно-акустичного профілювання істотно підвищує інформативність проведених досліджень.

Результати. Виконано аналіз традиційних електрометричних і нових резонансно-акустичних геофізичних методів дослідження. Показана можливість вибору найкращих ділянок для будівництва та експлуатації трубопровідних транспортних систем. Розкрита ефективність комплексного застосування геофізичних методів при обґрунтуванні заходів захисту трубопровідних транспортних систем від впливу природних і техногенних процесів.

Наукова новизна. Уперше показане використання нового геофізичного методу резонансно-акустичного профілювання спільно з комплексом традиційних методів електрометрії на таких складних і відповідальних інженерних спорудах як трубопровідні транспортні системи України.

Практична значимість. Використання методу резонансно-акустичного профілювання для вивчення геологічного розрізу, картування зон зсувів, обвалів, обводнених, виділення водоносних горизонтів і зон тектонічних порушень, виявлення карстових зон, а також для дослідження ділянок можливих місць витоків рідкого або газоподібного наповнювача через пошкодження у трубопроводах. Визначення можливих ділянок корозії на трубопровідних транспортних системах методами електророзвідки – ВЕЗ (вертикальне електричне зондування), „віддаленого електрода“, вимірювання градієнт потенціалу та СЕП (симетричне електричне профілювання).

Ключові слова: *трубопровідні транспортні системи, вертикальне електричне зондування, симетричне електричне профілювання, метод „віддаленого електрода“, вимірювання градієнт потенціалу*

Цель. Рассмотрение и анализ наиболее информативных и перспективных геофизических методов исследования природных и техногенных процессов, которые влияют на проектирование и безопасную эксплуатацию трубопроводных транспортных систем Украины.

Методика. Предложено использование комплекса геофизических исследований для инженерных изысканий при проектировании и эксплуатации линейных подземных сооружений трубопроводного транспорта Украины. Использование традиционных методов электрометрии совместно с новым методом резонансно-акустического профилирования существенно повышает информативность проведенных исследований.

Результаты. Выполнен анализ традиционных электрометрических и новых резонансно-акустических геофизических методов исследования. Показана возможность выбора наилучших участков для строительства и эксплуатации трубопроводных транспортных систем. Раскрыта эффективность комплексного применения геофизических методов при обосновании мер защиты трубопроводных транспортных систем от воздействия природных и техногенных процессов.

Научная новизна. Впервые показано использование нового геофизического метода резонансно-акустического профилирования совместно с комплексом традиционных методов электрометрии на таких сложных и ответственных инженерных сооружениях как трубопроводные транспортные системы Украины.

Практическая значимость. Использование метода резонансно-акустического профилирования для изучения геологического разреза, картирования зон оползней, обвалов, обводнений, выделения водоносных горизонтов и зон тектонических нарушений, выявления карстовых зон, а также для исследования участков возможных мест утечек жидкого или газообразного наполнителя через повреждения в трубопроводах. Определение возможных участков коррозии на трубопроводных транспортных системах методами электроразведки – ВЭЗ (вертикальное электрическое зондирование), „удаленного электрода“, измерения градиент потенциала и СЭП (симметричное электрическое профилирование).

Ключевые слова: *трубопроводные транспортные системы, инженерные изыскания, вертикальное электрическое зондирование, симметричное электрическое профилирование, метод „удаленного электрода“, измерения градиент потенциала*

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