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The use of hydrogels in mixtures to reduce the transient resistance of the soil - grounding device

Siarhei Baraishuk[1], *Ivan* Pavlovic[1], *Muzaffar* Murodov[1*], *Murodjon* Nabiev[2]

[1]Department of Practical Training of Students, Belarusian State Agrarian Technical University, Minsk, Belarus
[2]Department of Energy, Namangan Engineering-Construction Institute, Namangan, Uzbekistan

Abstract. A method for reducing the resistance of the ground loop for high-resistance soils by using mixtures based on hydrogel is considered as backfill materials. Based on the results of the research, an analysis was made of the effect of mixtures on soil resistivity, the seasonality factor and the resistance of the ground loop at various temperatures and humidity.

1. Introduction

The electrical resistance to the spreading current of grounding devices depends on many factors, such as the electrical resistance of the ground electrode materials, the quality of the contact connections of the ground loop elements, and the loop configuration. But the most important role is played by the resistivity of the soil in the near-electrode space, its porosity, moisture content, and the seasonal coefficient of change in soil resistivity.

The soil resistivity at the point of contact of the grounding device with the soil determines the qualitative and quantitative characteristics of the current spreading. Its value determines the type of contour and its geometric parameters. At high values of soil resistivity, the contour dimensions may become unacceptable. At the same time, to ensure the specified technical characteristics of the circuit, various methods of influencing the ground at the place of grounding installation can be used.

The resistance to current spreading of the grounding device depends on the types of soil (sand, clay, limestone), the size and density of particles, humidity and temperature, as well as the chemical composition of the soil, the presence of acids, salts, alkalis in it [1, 2]. For the seasonal Influences in soil resistivity, in turn, the determining parameters are humidity and temperature [2 - 4]. It can be concluded that an increase in the ability of the soil to retain water, with minerals and salts dissolved in it, in the near-electrode space improves the properties of the grounding device.

According to previously known data [3], the optimal content for the dissolution of mineral salts is soil moisture content of more than 16%. From the graph (Fig. 1) it can be seen that when the moisture content of the mixture is less than 18%, the specific electrical resistance of the soil increases, since the transport function of mineral salts dissolved in the soil decreases. Sufficient soil moisture at the installation site of the grounding device is an important component of a stable value of the electrical resistance of the ground loop. Hence the need to maintain soil moisture constant. This can be achieved by transferring the circuit to a soil area with high humidity (for example, a wetland), deepening to groundwater (vertical modular ground electrode systems), and periodically moistening the location of the grounding device. In addition, there are recommendations for the use of backfill with moisture-retaining substances, for example, from bentonite clays. We also suggested using hydrogel additives.

Thus, the ground electrode will work best around which an area with good contact, optimal humidity and concentration of mineral and conductive substances is formed in the soil.

Another important factor of influence is the ability to perform its functions at different temperatures. In particular, at negative temperatures, unbound moisture in the soil freezes, while the electrical resistance of the soil is high [3-5], and when thawed, everything returns. This also leads to the need to bind the liquid to reduce the effect of its freezing.

Fluctuations in the resistance of grounding devices during the year leads to the need to increase the number of electrodes in the circuit, the depth of their occurrence, in order to compensate for the increase in resistance. The need to provide a regulated value of grounding resistance leads to overconsumption of materials of grounding conductors, an increase in the

[*]Corresponding author: m_murodov@mail.ru

volume of installation work, which leads to an increase in costs. When installing ground loops, various methods are used to reduce the resistance of grounding devices, such as the use of various types of electrode materials, as well as the use of various types of additives (electrolytes) and replacing the soil in the near-electrode space with another having a lower resistivity than the original soil, and some other [7-10].

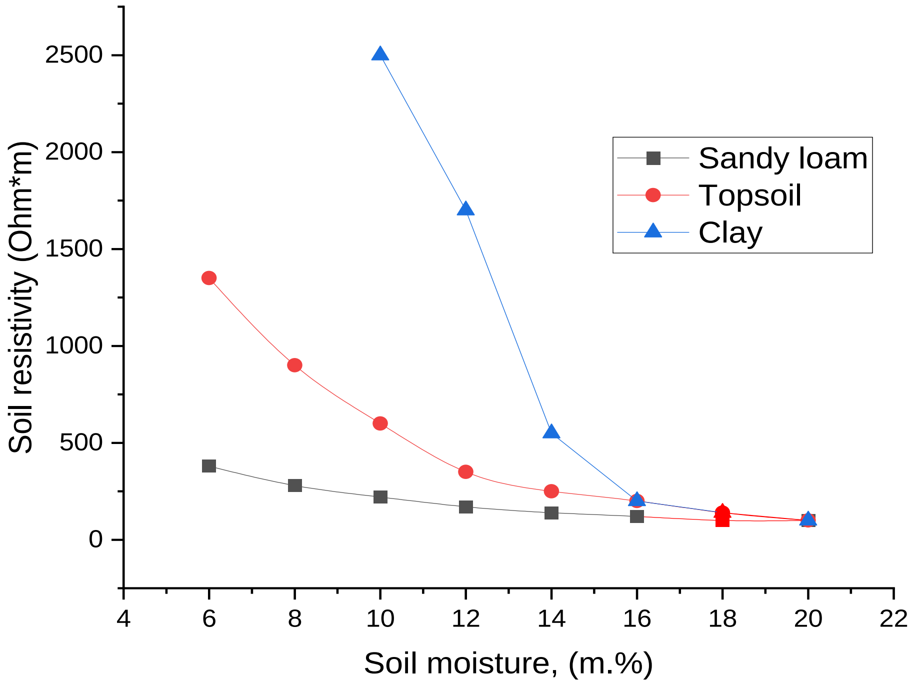

Fig. 1. The dependence of the mixture resistance on humidity

According to known studies, soil resistivity can be reduced by the use of sodium chloride, magnesium sulfate, copper sulfate and calcium chloride or similar substances in the near-electrode space [2, 10, 11]. The most widely used is the use of table salt and magnesium sulfate. The method of using these chemicals is reduced to the treatment of the near-electrode space, so that there is no direct contact with the electrode of the grounding device, in order to avoid the activation of corrosion processes. This treatment must be repeated periodically, since substances are washed out, their use also increases the rate of corrosion of the materials from which the ground loop is made. To prevent the rapid destruction of the electrodes, it becomes necessary to use protective coatings, which must have sufficient conductivity.

Previously, we proposed a method for reducing the electrical resistivity of soil based on the use of carbon-containing powders together with water-retaining additives and plasticizers. In this work, we studied the effect of hydrogel concentration on conductivity. Replacement of part of the soil in the near-electrode space with this mixture can reduce soil resistance [11]. Such a mixture can also be used as a filler for matrices around the electrode, for example, concrete shells or sleeves made of conductive and filtering material, as geotextiles.

The decrease in this indicator is due to the fact that the hydrogel binds moisture in the soil. Water associated with the hydrogel does not wash away minerals from the soil, and when introduced into the mixture of carbonaceous fillers and clay, it allows to further reduce the resistance of the soil. In addition, the use of this method allows to reduce the freezing temperature of the soil. When studying the effect of the mixture used based on cross-linked copolymers of potassium and ammonium salts of acrylic acid on the seasonality factor, it was possible to determine that it is reduced to 20% compared to the control ground electrode.

2. Experimental Part

2.1 Field Experiment

When conducting full-scale experiments on sandy loam soil, grounding devices (ground loops) were mounted, which are a vertical composite electrode made of galvanized steel with a diameter of 16 mm and a depth of 3 m and a horizontal fragment of a connecting strip 4x50 mm of the 3 meters length. The reference devices were assembled without the use of any additives. In the near-electrode volume of the soil of the experimental contours, treatment was carried out with a mixture with different concentrations of hydrogel and graphite, or with its individual components. Systematic

measurements of the resistance values of grounding devices were carried out for more than four years by a four-wire method using a grounding device resistance meter Sonel MRU-200 at different temperatures and humidity of the environment and soil, the error of such measurements did not exceed 10%.
The four-wire method Fig. 2 for measuring the resistance of a grounding device is based on determining the voltage between the grounding device and the potential pin and the current in the loop formed by the ground, the current pin and the measuring device.

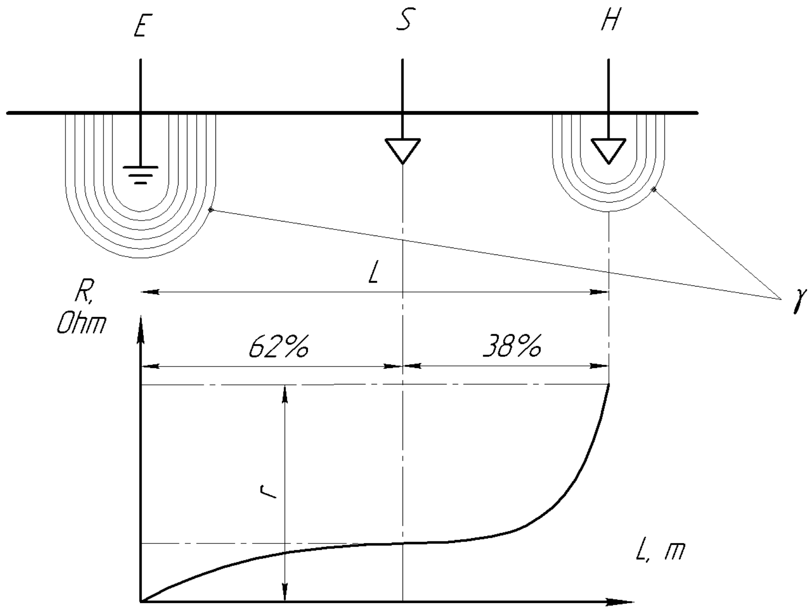

Fig. 2. Determination of the zero-potential point by the 62% method: E - grounding conductor; S - voltage electrode; H - current electrode; L - distance between electrodes; r - current electrode resistance; γ - area of effective resistance of the electrode

This measurement scheme is one of the main ones, it is used to more accurately determine the resistance of the grounding device, which makes it possible to eliminate the influence of the resistance of the measuring wires, as well as reduce the influence of stray currents in the soil. The essence of the technique is to install in the ground near the grounding device (E) measuring electrodes of current (H) and potential (S). The electrode S is placed on the same line between the circuit under test and the current electrode in the area of zero potential. The device measures the amount of current flowing in the created circuit, and the voltage between the investigated ground electrode and the voltage electrode. The result of the measurement is the resistance value of the grounding device, calculated according to Ohm's law.
In addition, a series of measurements of the electrical resistivity of the soil at the site of the experimental and reference circuits was carried out using the method of vertical electrical sounding.

3. Laboratory experiment

Laboratory measurements of soil resistivity depending on the amount of introduced hydrogel, humidity and temperature were carried out according to the method similar to that described in [12] and present in Fig. 3.
Studies were carried out on the dependence of the electrical resistivity of the mixture on temperature. To do this, the entire measuring cell shown in Fig. 3 A cell made of Plexiglas, rectangular in shape with internal dimensions: a=100 mm; b=45 mm, h=45 mm. External electrodes (A, B) 44x40 mm in size (40 mm - electrode height) in the form of rectangular stainless steel plates with a leg to which the conductor-current lead is attached, while one side of each plate, which is adjacent to the end surface of the cell, is isolated; internal electrodes (M, N) made of copper wire or rod with a diameter of 1 to 3 mm and a length of 10 mm more than the height of the cell.
External electrodes are installed close to the inner end surfaces of the cell. When collecting the cell, the plates are placed to each other with non-insulated sides. Then the mixture was placed into the cell, and it was compacted in layers. The internal electrodes were installed vertically, lowering them to the bottom along the central line of the cell at a distance of 50 mm from each other and 25 mm from the end walls of the cell.
The electrical resistivity of the mixture ρ, Ohm•m, was calculated by the formula:

$$\rho = \frac{U \times S}{I \times R_{MN}} \quad (1)$$

where U – is the voltage drops between the two inner electrodes, V;
I - current strength in the cell, A;
S - surface area of the working electrode, m;
R_{MN} - distance between internal electrodes, m.

The electrical resistivity of the mixture was determined by a four-electrode circuit at direct current. External electrodes with the same working surface area S are polarized with a current of a certain strength and the voltage drop V is measured between two internal electrodes at a distance between them.

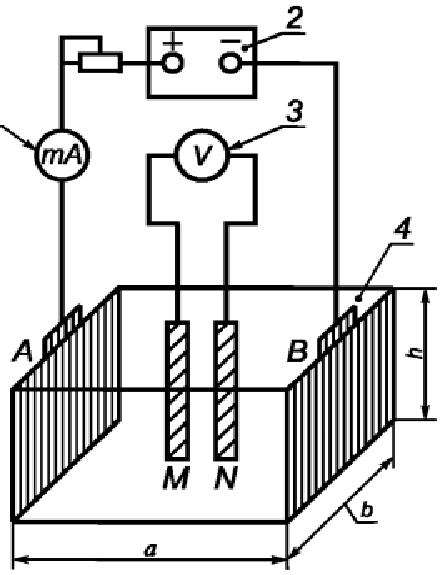

Fig. 3. Scheme of the installation for determining the electrical resistivity of the soil in the laboratory. 1 - milliammeter; 2 - current source; 3 - voltmeter; 4 - measuring cell

4. Results and Discussion

The results of studies of experimental circuits are shown in Fig. 4. The resistances of the reference grounding device (grey curve) as well as devices with the mixture composition being developed (blue curve) are shown in Fig. 4. The dynamics of measuring the resistance of a grounding device treated with one component was also analyzed: hydrolyzed polyacrylonitrile (red curve). Because hydrolyzed polyacrylonitrile is the main moisture stabilizing component of the mixture.

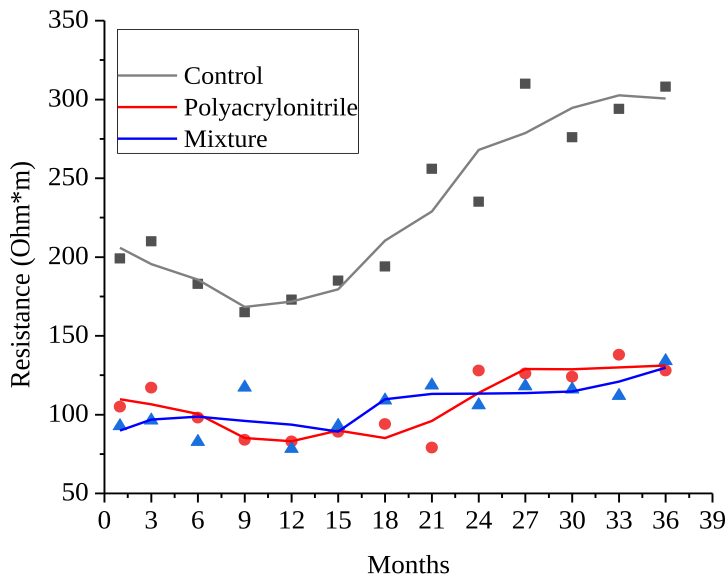

Fig. 4. Results of continuous measurements of real grounding devices for 3 years

From the obtained measurement results, it can be concluded that the grounding device has the lowest resistance value, the near-electrode space of which is treated with an experimental mixture to reduce the spreading resistance of grounding devices containing hydrogel and graphite. The use of mixtures allows not only to reduce fluctuations in the spreading resistance of the ground loop, but also to reduce its resistance in comparison with the control loop.
The graphs show a strong influence of climatic fluctuations on the electrical resistance of the control grounding device (red line) and its significant decrease with the use of hydrosorbs in the backfill (sulfur and blue lines), this phenomenon was described in more detail by us earlier in [13]. As can be seen from the graphs, the influence of seasonality when using mixtures and hydrogel is reduced to 20% compared to a reference grounding device. And if, during the installation of vertical electrodes, their near-electrode space is also treated with a mixture, - up to 25% compared to the control values. At the same time, the use of conductive additives in mixtures makes it possible to reduce the resistance to current spreading by up to 3 times with the same configuration of grounding devices.
Fig. 5 shows the results of measurements of the specific resistance of a mixture of soil with hydrolyzed polyacrylonitrile in various proportions.

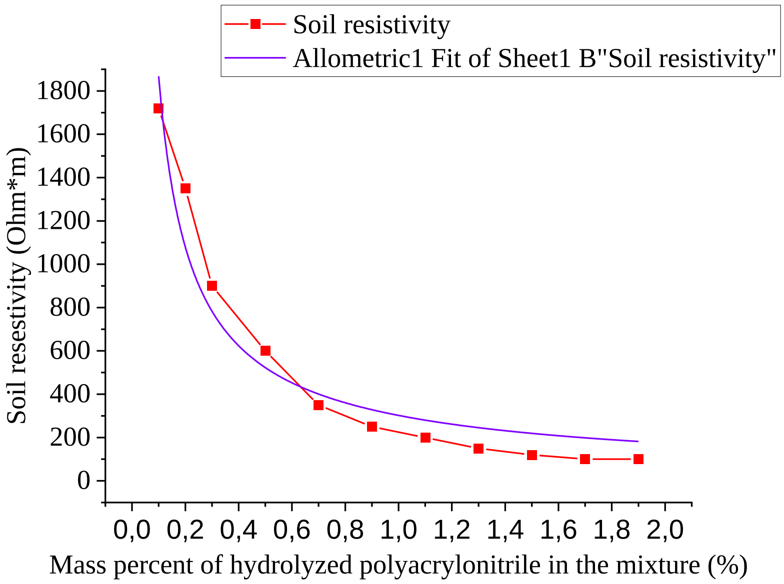

Fig. 5. The results of measurements of the specific resistance of a mixture of soil with hydrolyzed polyacrylonitrile in various proportions

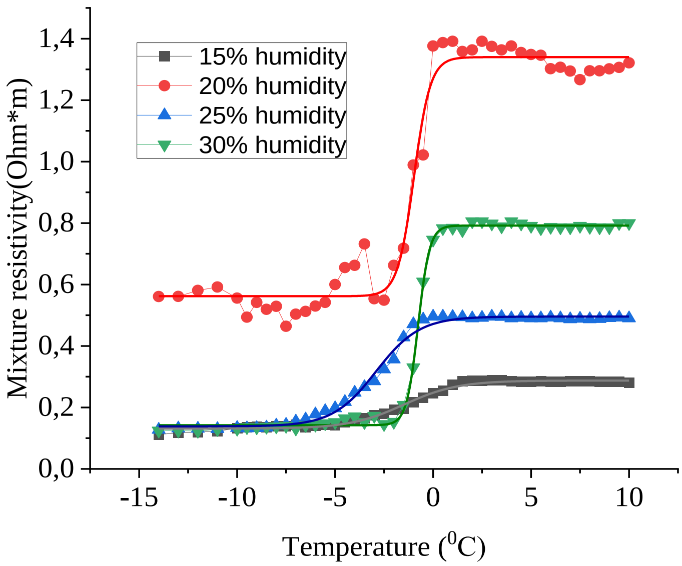

Fig. 6. The dependence of the resistivity of the mixture on temperature

As can be seen from the graph presented in Fig. 5, when hydrogels obtained by swelling of hydrolyzed polyacrylonitrile with a dry weight of more than 1.3–1.5% of the soil mass are introduced, moisture stabilization occurs, and a further increase in concentration does not lead to a decrease in soil resistivity, which indirectly indicates to obtain optimal soil moisture, which is in good agreement with the results presented in [1-4].
To measure the resistance, a sample of the mixture was poured with distilled water to the required mass fraction of water content and frozen to -20°C, and then gradually thawed at room temperature.
For example, Fig. 6 shows the results of a study for a mixture containing 18% graphite and 1.5% hydrogel in the composition.
As can be seen from the graph, the freezing temperature is from -3.5 to -2^{0}C. In addition, on the graph for such a composition of the mixture, we see an anomalous (in comparison with those known from works [2, 4, 6] for ordinary types of soils) behavior of resistivity, namely, its decrease when the mixture freezes. Such a phenomenon can be interpreted by the consolidation of the conductive parts of the graphite contained in the mixture.
When studying the influence of the mixture on the seasonal factor, it was found that when a horizontal strip is filled with a mixture, the seasonal resistance coefficient is reduced to 20% compared to the control grounding device.
If, when installing vertical electrodes, their near-electrode space is also treated with a mixture (when installing modular earth electrodes, the bushing, passing through the soil, expands the hole in the soil and this space is filled with a waterlogged mixture), the seasonal resistance coefficient in this case decreases to 25% compared to the control values for the initial scheme.

5. Conclusion

In the course of the research, an anomalous change in the resistivity of the mixture for measurement in the process of temperature change was established when using hydrosorbable compositions based on polyacrylonitrile hydrolyzate in combination with dispersed graphite in their composition. Many years of field experience has shown that the use of such mixtures when backfilling grounding devices can reduce the seasonal resistance coefficient fluctuations on the ground loop by up to 25%, as well as reduce the resistance of the grounding device by 3 times.
Compared to known compositions using mineral and electrically conductive additives, the proposed method stabilizes the resistance along the circuit by binding moisture to the hydrogel, which makes such a composition more effective.
The next direction of research will be to study the possibility of further reducing the freezing point of the soil and establishing the effect of the mixture on the corrosion of the elements of the grounding device.

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