DOI 10.52209/1609-1825_2022_2_348 UDC 621.3.053.1

Influence of Soil Density on Its Resistivity

[1]**ZAYTSEVA Natalia,** *Cand. of Tech. Sci., Associate Professor, zaitzevns@mail.ru,*
[2]***ISSABEKOVA Bibigul,** *PhD, Associate Professor, asbizh@mail.ru,*
[2]**ISSAVEKOV Zhanat,** *PhD, Associate Professor, zh_is@mail.ru,*
[3]**ZHANTLESSOVA Assemgul,** *PhD, Senior Lecturer, asbizh@mail.ru,*
[4]**NOVOZHILOV Timofey,** *Cand. of Tech. Sci., Associate Professor, timokvey@mail.ru,*
[1]*Innovative University of Eurasia, Kazakhstan, Pavlodar, Lomov Street, 45,*
[2]*Toraighyrov University, Kazakhstan, Pavlodar, Lomov Street, 64,*
[3]*S. Seifullin Kazakh Agrotechnical University, Kazakhstan, Nur-Sultan, Zhenis Avenue, 62,*
[4]*Omsk State Technical University, Russia, Omsk, Mira Avenue, 11,*
**corresponding author.*

Abstract. *When calculating the electrical resistance of the grounding devices of electrical installations, it is necessary to know the resistivity ρ of the soil. As you know, resistivity depends on many parameters, including such as density and type of soil. To determine this dependence, an experimental setup was created, where experiments were carried out on compaction of various types of soil, teak like loam, sandy loam and sand. Dependences of resistivity are found on the basis of pilot studies of ρ soil from its density what allowed specifying dynamics of its change during soil consolidation from a loosening condition to density of a natural bedding of soil. Experiments have shown that the statement «the better the soil is rammed, the lower its electrical resistivity» works, but not for all soils. The technique we propose allows us to determine and build these dependencies, select or refine the worst-case resistivity value relative to the data of the geological prospecting center for each soil layer, build their graphs of changes over time to calculate the resistance of ground electrodes and their design. This technique can be used to build dependencies for other types of soil. The technique can be applied as an additional one to others, but it gives a more accurate calculation of resistance for complex structures of grounding devices.*

Keywords: *soil, density, resistance, resistivity of the soil, earthing devices, temperature, humidity, electrical conductivity, degree of soil compaction, soil measurements, laboratory measurements.*

Relevancy

At calculation of electric resistance [1-12] of earthing devices of electrical installations, it is necessary to know resistivity ϱ soil that influences temperature, humidity and degree of compaction of soil. Before publishing articles [5,6], where dependence ϱ from temperature and humidity of the soil received on the basis of indistinct logic and dependence of temperature of soil on its depth is presented, ϱ with empirical formulas or directly through labor consuming measurements was calculated. These measurements were corrected with coefficients reflecting seasonal factors. Definition on [6] appeared more accurate, but also it doesn't consider change of ϱ depending on soil density. It is considered, as well as in other cases that soil will be well stamped and its density thus will reach the level that has been presented before the instalment of earthing devices [10-12]. Meanwhile, it is known that often after installation of grounding devices their accuracy gets worse compared to the calculated parameters despite careful observance of technology of carrying out constructional work. There is data on subsidence of soil that defines temporary intervals of soil transition to a condition of natural bedding of soil. For example, it is required at systematically erected construction of grounding with application to ram carefully the soil of clay and sand. It requires approximately 2 to 5 years and 1-2 years with ramming, and without it roughly 10 to 15 and 2-5 years. Thus, both of the enforced ramming and time of natural ramming affect the soil density.

Method for determining the electrical resistivity of the soil. The fact that the more soil is rammed the less electric resistance it has, that is clear on a physical level and is common knowledge. However, the nature of the dependence ϱ soil from its density for sand, sandy loam and loam, are studied insufficiently. In this work, these received dependences on installation, that allow providing necessary consolidation of samples of a concrete type of soil are presented. This work also presents measurements of soil electric conductivity at various degrees of their density. Installation [13] (figure 1) consists of a pipe 1 in diameter of 11 cm fixed vertically on a frame 2 established on elastic support 3, with the activator of the fluctuations 4, two internal electrodes 5 and 6, placed in two radial openings 7 executed in an

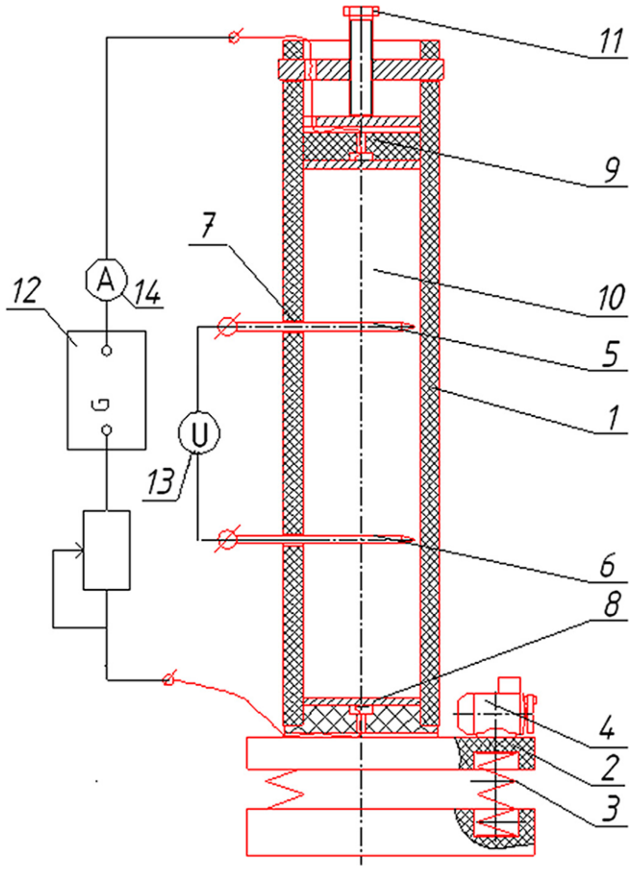

Figure 1 – Installation for definition of soil electrical conductivity

average part of a pipe. The bottom external electrode 8 is established motionlessly in the bottom of a pipe, and top external 9 – at the top of a pipe, with a clip possibility to a sample of the soil 10 placed in a pipe, for example the screw 11. External electrodes are attached to the power supply 12, and internal – to the voltmeter 13.

Experiments were carried out as follows: 1) the sample of soil with known weight of P and humidity of v was loaded into a pipe with a segment of S, length of ℓ_t, and temperature of t; 2) it was exposed to a vibration process for achievement of some form of compression; 3) tension with frequency of 50 Hz was applied on external electrodes. The current passing through soil, was measured by the amperemeter 14, and the tension on internal electrodes by the voltmeter 13; resistivity counted on $\rho=(U \cdot S)/(I \cdot \ell)$, where ℓ – distance between internal electrodes 6 and 7; 4) the density of d was determined by a known formula: $d=P/(S \cdot \ell_t)$. 5) Then installation disconnected from a tension source, and partially consolidated soil was exposed to a vibration process for some time. After the next stage of consolidation tension again applied, and measurements were carried out. These actions had been proceeded before the sample's consolidation was close to the limits.

Apparently from figure 2 and figure 3 for damp soils (sand, sandy loam and loam) from 1% to the water-saturation consolidation ρ decreases when density increases. For example, for sand with humidity of 1% and 10% dependency of ρ from density could be described by the following exponent:

$$\rho = \rho_{d_0} e^{k_v(d-d_0)},$$

where ρ_{d0} and d_0 – have resistivities and the soil density is taken accordingly to geological exploration which were undertaken before designing the earthing device, – the factor equal $k_v = -e^{(-0.08 \cdot v + 1.08)}$.

Humidity makes a very strong impact on dependence ρ from d. So at dry sand (humidity of 0%) ρ changes within 9,5-7,5 KOm·m, at damp sand (10%) ρ changes from 100 to 35 Om·m. Dependency ρ of d at humidity from 1% to 10% changes in 2,5-3 times, and the value of d decreases in 10-100 times (figure 2 a scale ρ_1 and ρ_2).

Nature of changes of ρ for sandy soil in dry condition (from 0% to 1%) has its own particular qualities: at the beginning of consolidation process the reduction of d of sand that could be described by an exponent, is observed approximately until $1.6 \cdot 10^3$ kg/m^3 then unlike the data [4] it has a linear growth (figure 2, a curve ρ_3) is observed.

For sandy loam and loam it was impossible to receive these dependencies, because in reality they have no humidity less than 1,5% and 1% respectively since they are highly hydroscopic (figure 3). Therefore damp soil (sand, sandy loam and clay) is necessary to ram carefully, as well as it is recommended in [4].

For loams and clay in a damp condition the phenomenon of particle adhesion is typical. It leads to formation of emptiness and numerous cracks that reduce conductivity of soil. Therefore it is necessary to consider this feature at the installation of the devices. It was possible to receive approximately homogeneous density soil structure for loam humidity up to 10% (figure 3) at the laboratory installation.

Considering that ρ without consolidation at a natural bedding of soil is much less than soil that not so carefully rammed (if not to ram soil at all, as you can see from demonstrated dependencies, ρ may reach 300%) the received results can be used for adjustment parameters of the earthing device electrical installations from the moment of their bookmark before complete land subsidence.

This research has been funded by the Science Committee of the Ministry of Education and Science of the Republic of Kazakhstan (Grant No. AP13268889).

Conclusions

Limits of ρ measurements depending on density at the same humidity for loams and clay are highly diverse and should be considered at calculations ρ, without watching even at a careful ramming.

For damp soil resistivity decreases exponentially, for sandy dry (at humidity of 0%) – after an exhibitor to density $1{,}55\text{-}1{,}6 \cdot 10^3$ kg/m^3 at first decrease, then linearly grows.

The received results can be used at the parameters adjustment for earthing device at electrical installations.

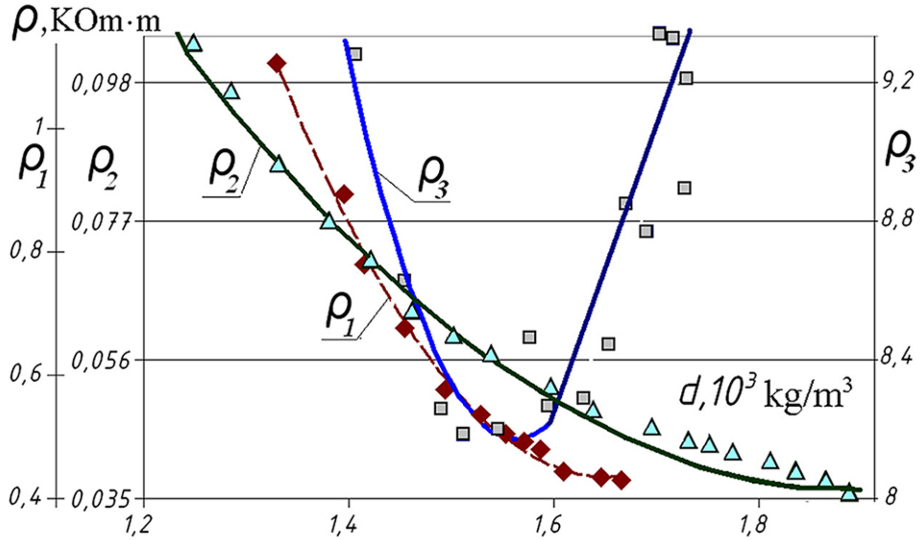

Figure 2 – Dependences ρ from density for sand humidity of 1% (a curve ρ_1), 10% (a curve ρ_2) and 0% (a curve ρ_3)

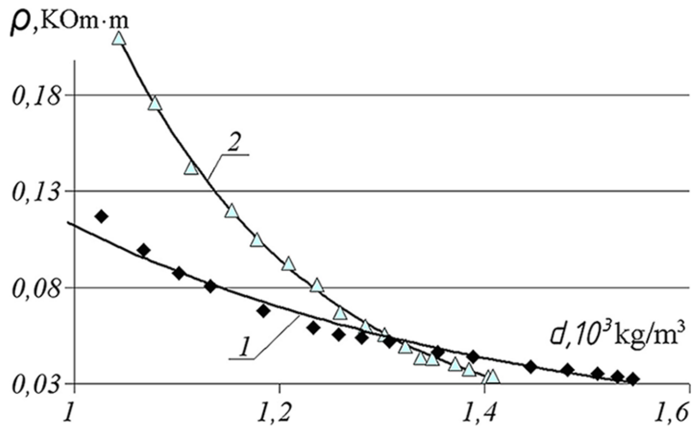

Figure 3 – Dependences ρ from density for sandy loam humidity of 5% (a curve 1) and loam of 7% (a curve 2)

REFERENCES

1. Nahman, J., Paunovic, I. Resistance to earth of earthing grids buried in multi-layer soil, Electrical Engineering, 88, 2006, pp. 281-287. DOI: 10.1007/s00202-004-0282-y
2. Nahman, Jovan M., and J. M. Nahman. Dependability of engineering systems. Elektroprivreda 2002.1, 2002, pp. 102-102.
3. Tevan, György. Calculation of Overvoltages Caused by Lightning Strokes in the Tower of an Overhead Line. Periodica Polytechnica Electrical Engineering (Archives) 45.1, 2001, pp. 23-41.
4. N.M. Nor, A. Haddad, H. Characterization of ionization phenomena in soils under fast impulses, IEEE Transactions on Power Delivery, 21, 2006, pp. 353-361. DOI: 10.1109/TPWRD.2005.852352
5. Kazmi, Danish, et al. Exploring the relationship between moisture content and electrical resistivity for sandy and silty soils. International Journal of Engineering Science Invention 5.6, 2016, pp. 33-35.
6. Kletsel, M.Ya., Zaytseva, N.M., Isabekova B.B. Determination of temperature of soil on depth of grounding conductors, Russian Electrical Engineering. 86, 2015, pp. 275-281. DOI:10.3103/S1068371215050119
7. Tikhomirov, A.A., Pshenichnikov M.A. Two-layer earthing device in electric-power engineering based on shungite, ENGINEERING, 05(95), 2020. DOI: 10.23670/IRJ.2020.95.5.012
8. Caetano, C.E.F. et al. A simplified method for calculating the impedance of vertical grounding electrodes buried in a horizontally stratified multilayer ground, 34th International Conference on Lightning Protection (ICLP) IEEE, 2018, pp. 1-7. DOI:10.1109/ICLP.2018.8503460
9. Batista, R., Paulino, J.O.S. A practical approach to estimate grounding impedance of a vertical rod in a two-layer soil, Electric Power Systems Research. 177: 105973, 2020. DOI: 10.1016/j.epsr.2019.105973
10. Zhou, Mi, et al. Laboratory investigations on factors affecting soil electrical resistivity and the measurement. IEEE Transactions on Industry Applications 51.6, 2015, pp. 5358-5365.
11. Bertermann, David, and Hans Schwarz. Bulk density and water content-dependent electrical resistivity analyses of different soil classes on a laboratory scale. Environmental Earth Sciences 77.16, 2018, pp. 1-14.

12. Abidin, M.H.Z., et al. The influence of basic physical properties of soil on its electrical resistivity value under loose and dense condition. Journal of Physics: Conference Series. Vol. 495. No. 1. IOP Publishing, 2014.
13. № 20839. Установка для определения электропроводности грунта. 16.02.2009. бюл. № 2.

Топырақ тығыздығының оның электр кедергісіне әсері

[1]***ЗАЙЦЕВА Наталья Михайловна,*** *т.ғ.к., доцент, zaitzevns@mail.ru,*
[2]****ИСАБЕКОВА Бибігүл Бейсембайқызы,*** *PhD, доцент, asbizh@mail.ru,*
[2]***ИСАБЕКОВ Жанат Бейсембайұлы,*** *PhD, доцент, zh_is@mail.ru,*
[3]***ЖАНТЛЕСОВА Әсемгүл Бейсембайқызы,*** *PhD, аға оқытушы, asbizh@mail.ru,*
[4]***НОВОЖИЛОВ Тимофей Николаевич,*** *т.ғ.к., доцент, timokvey@mail.ru,*
[1]Инновациялық Еуразия университеті, Қазақстан, Павлодар, Ломов көшесі, 45,
[2]Торайғыров университеті, Қазақстан, Павлодар, Ломов көшесі, 64,
[3]С. Сейфуллин атындағы Қазақ агротехникалық университеті, Қазақстан, Нұр-Сұлтан, Жеңіс даңғылы, 62,
[4]Омбы мемлекеттік техникалық университеті, Ресей, Омбы, Мира даңғылы, 11,

**автор-корреспондент.*

Аңдатпа. *Электр қондырғыларының жерге қосу құрылғыларының электрлік кедергісін есептеу кезінде топырақтың ρ электрлік кедергісін білу қажет. Белгілі болғандай, электр кедергісі көптеген параметрлерге, соның ішінде тығыздық пен топырақтың түріне байланысты. Бұл тәуелділікті анықтау үшін эксперименттік қондырғы құрылды, онда топырақтың әртүрлі түрлерін, саздақ, құмдақ және құм сияқты тиктерді тығыздау бойынша эксперименттер жүргізілді. Эксперименттік зерттеулер негізінде топырақтың нақты электр кедергісінің топырақтың тығыздығына тәуелділігі табылды, бұл топырақтың шоғырлану жағдайынан топырақтың табиғи толтырылу тығыздығына дейін өзгеру динамикасын нақтылауға мүмкіндік берді. Тәжірибелер «топырақ неғұрлым жақсы тығыздалған болса, оның электрлік кедергісі соғұрлым аз болады» деген тұжырымның жұмыс істейтінін дәлелдеді, бірақ барлық топырақтар үшін емес. Біз ұсынып отырған әдістеме осы тәуелділіктерді анықтауға және құруға, топырақтың әрбір қабаты үшін геологиялық барлау орталығының деректеріне қатысты меншікті электр кедергісі мәнінің ең нашар нұсқасын таңдауға немесе нақтылауға, жерге тұйықтағыштардың кедергісін есептеу және оларды жобалау үшін уақыттан бастап олардың өзгеру графиктерін жасауға мүмкіндік береді. Осы әдістеме бойынша топырақтың басқа түрлеріне тәуелділікті құруға болады. Техниканы басқаларға қосымша ретінде қолдануға болады, бірақ жерге қосу құрылғыларының күрделі құрылымдары үшін кедергіні дәлірек есептеуге мүмкіндік береді.*

Кілт сөздер: *топырақ, тығыздық, қарсылық, топырақтың меншікті электрлік кедергісі, жерге қосу құрылғылары, температура, ылғалдылық, электр өткізгіштігі, топырақтың тығыздалу дәрежесі, топырақты өлшеу, зертханалық өлшеу.*

Влияние плотности грунта на его удельное электрическое сопротивление

[1]***ЗАЙЦЕВА Наталья Михайловна,*** *к.т.н., доцент, zaitzevns@mail.ru,*
[2]****ИСАБЕКОВА Бибигуль Бейсембаевна,*** *PhD, доцент, asbizh@mail.ru,*
[2]***ИСАБЕКОВ Жанат Бейсембаевич,*** *PhD, доцент, zh_is@mail.ru,*
[3]***ЖАНТЛЕСОВА Асемгуль Бейсембаевна,*** *PhD, старший преподаватель, asbizh@mail.ru,*
[4]***НОВОЖИЛОВ Тимофей Николаевич,*** *к.т.н., доцент, timokvey@mail.ru,*
[1]Инновационный Евразийский университет, Казахстан, Павлодар, ул. Ломова, 45,
[2]Торайгыров университет, Казахстан, Павлодар, ул. Ломова, 64,
[3]Казахский агротехнический университет имени С. Сейфуллина, Казахстан, Нур-Султан, пр. Женис, 62,
[4]Омский государственный технический университет, Россия, Омск, пр. Мира, 11,

**автор-корреспондент.*

Аннотация. *При расчете электрического сопротивления заземляющих устройств электроустановок необходимо знать удельное электрическое сопротивление ρ грунта. Как известно, удельное электрическое сопротивление зависит от множества параметров, в том числе и таких, как плотность и вид грунта. Для определения этой зависимости была создана экспериментальная установка, где проводились эксперименты по уплотнению разного вида грунта, таких как суглинок, супесь и песок. Были найдены зависимости удельного электрического сопротивления грунта на основании экспериментальных исследований ρ грунта от его плотности, что позволило уточнить динамику его изменения при консолидации грунта от состояния разрыхленности до плотности естественной засыпки грунта. Эксперименты доказали, что утверждение «чем лучше утрамбован грунт, тем меньше его удельное электрическое сопротивление» работает, но не для всех грунтов. Предлагаемая нами методика позволяет определять и строить эти зависимости, выбрать или уточнить самый наихудший вариант значения удельного электрического сопротивления относительно* *данных геологоразведочного центра для каждого слоя грунта, строить их графики изменения от времени для расчета сопротивлений заземлителей и их проектирования. По этой методике можно построить зависимости и по другим видам грунта. Методика может применяться как дополнительная к другим, но дающая более точный расчет сопротивления для сложных конструкций заземляющих устройств.*

Ключевые слова: *грунт, плотность, сопротивление, удельное электрическое сопротивление грунта, заземляющие устройства, температура, влажность, электропроводность, степень уплотнения грунта, измерения грунта, лабораторные измерения.*

REFERENCES

1. Nahman, J., Paunovic, I. Resistance to earth of earthing grids buried in multi-layer soil, Electrical Engineering, 88, 2006, pp. 281-287. DOI: 10.1007/s00202-004-0282-y
2. Nahman, Jovan M., and J. M. Nahman. Dependability of engineering systems. Elektroprivreda 2002.1, 2002, pp. 102-102.
3. Tevan, György. Calculation of Overvoltages Caused by Lightning Strokes in the Tower of an Overhead Line. Periodica Polytechnica Electrical Engineering (Archives) 45.1, 2001, pp. 23-41.
4. N.M. Nor, A. Haddad, H. Characterization of ionization phenomena in soils under fast impulses, IEEE Transactions on Power Delivery, 21, 2006, pp. 353-361. DOI: 10.1109/TPWRD.2005.852352
5. Kazmi, Danish, et al. Exploring the relationship between moisture content and electrical resistivity for sandy and silty soils. International Journal of Engineering Science Invention 5.6, 2016, pp. 33-35.
6. Kletsel, M.Ya., Zaytseva, N.M., Isabekova B.B. Determination of temperature of soil on depth of grounding conductors, Russian Electrical Engineering. 86, 2015, pp. 275-281. DOI:10.3103/S1068371215050119
7. Tikhomirov, A.A., Pshenichnikov M.A. Two-layer earthing device in electric-power engineering based on shungite, ENGINEERING, 05(95), 2020. DOI: 10.23670/IRJ.2020.95.5.012
8. Caetano, C.E.F. et al. A simplified method for calculating the impedance of vertical grounding electrodes buried in a horizontally stratified multilayer ground, 34th International Conference on Lightning Protection (ICLP) IEEE, 2018, pp. 1-7. DOI:10.1109/ICLP.2018.8503460
9. Batista, R., Paulino, J.O.S. A practical approach to estimate grounding impedance of a vertical rod in a two-layer soil, Electric Power Systems Research. 177: 105973, 2020. DOI: 10.1016/j.epsr.2019.105973
10. Zhou, Mi, et al. Laboratory investigations on factors affecting soil electrical resistivity and the measurement. IEEE Transactions on Industry Applications 51.6, 2015, pp. 5358-5365.
11. Bertermann, David, and Hans Schwarz. Bulk density and water content-dependent electrical resistivity analyses of different soil classes on a laboratory scale. Environmental Earth Sciences 77.16, 2018, pp. 1-14.
12. Abidin, M.H.Z., et al. The influence of basic physical properties of soil on its electrical resistivity value under loose and dense condition. Journal of Physics: Conference Series. Vol. 495. No. 1. IOP Publishing, 2014.
13. No. 20839. Installation for determining the electrical conductivity of the soil. 16.02.2009. Bulletin of Inventions no. 2.