Electrochemical Stabilization of Clayey Ground
by
B. A. Rzhanitzin

Translated from the Russian
by
V. P. Sokoloff

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Translator's Foreword

Laboratory and field data on electrochemical stabilization of clays, by three Russian authors, are here presented in translation. Abstracts of the Russian papers were published in May 1947 issue of the Engineering News Record (pp. 100-101). There exists also a small body of literature, in German and English, dealing with the electrochemical stabilization and related subjects. Elements of the electrochemical process were patented by Casagrande in Germany, shortly before the last war.

Results of the Russians and of others, including the German patent, appear to be sound and interesting accordingly. Mechanism of the electrochemical stabilization, however, appears to be surmised rather than established. Unless the mechanism of such stabilization is understood in detail, little progress may be expected in field applications of the electrochemical method.

Electroosmosis, a poorly reversible coagulation of the soil colloids, and introduction of exchangeable aluminum into the clay complex have been given credit for the ground-stabilizing effects of direct electrical current. Much remains to be done, as the reader may see, in developing further the theory of the method. A critical study is indicated, in this connection, by agencies or individuals qualified and equipped for basic research in soil physics. Optimum schedules for field treatments need be ascertained with particular care, to suit any given kind of material and environment. A wide range of variation, in such schedules, is most certainly to be encountered in dealing with materials as diverse in their composition and properties as are clays. Any generalization on relationships between soil, electrolytes, moisture, and current would be premature if based on the Russian work alone.

Stabilization of ground is a major engineering geologic problem of national interest. Needless to say, perhaps, that failures are to be expected, in laboratory and in the field, in this as well as in any other kind of research. To minimize probabilities of such failures, it may be recommended that investigators develop the electrochemical stabilization problem not merely against the relatively narrow background of soil mechanics, but with a certain feeling for geology, mineralogy, pedology, soil physics, and soil chemistry.

(Electrochemical Stabilization of Clayey Ground).

Rzhanitzin, B.A. (NIS Trésta No. 5 Narkomstróia)

(Research Institute of Trust No. 5, Commissariat of Construction). "Electrohimicheskoe Zakréplenie Glinistyh Groòntov" (In Rus.).

Soveschánie po Zakrepléniiu Gróontov i Górnyh Poród (Conference on Stabilization of Ground and Rock). I. Doklády (I. Reports).

Akadémiia Naúk SSSR (Academy of Sciences USSR).

Moskwá (Moskow). 1941. 168 pp. Pages 55-66.

INTRODUCTION

Recently developed new methods of stabilization of weak grounds (e.g. the silicate treatment) are based on injection of chemical solutions into the ground Such methods are applicable accordingly only to the kinds of ground that have the coefficient of filtration higher than 2 meters per 24 hours and permit pene tration of the chemical solutions under pressure. This limit, however, as it is shown by our experience in construction, excludes a numerous and an important class of grounds, stabilization of which is indispensable in many instance For example, digging of trenches and pits in clayey, silty, or sandy ground shows that all these types act like typical "floaters" (sluds? -S) in the presence of the ground water pressure. There were several instances in the canalization of the city of Moskow where the laying of trenches below the ground water level has led to extreme difficulties with clayey and silty ground.

Similar examples could be cited in mining, engineering hydrology, and railroad construction. For these reasons, the development of methods of stabilizing such difficult types of ground has become an urgent problem of our day.

In 1936, the author began his investigations, at the ground Stabilization Laboratory of VODGEO Institute, with direct electrical current as the means of stabilization of grounds. Experiments had shown that a large number of clayey types, following passage of direct electrical current, undergoes a transforma tion of its physico-chemical properties. It was established that the (apparent -S) density of the ground is substantially increased in consequence of the application of direct electrical current. The ground loses also its capacity to swell and to soften in water. Later, after a more detailed study of the physico-chemical mechanism of the electrical stabilization, it became possible to develop the method so as to make it applicable to sandy and silty as well as to clayey ground. By this time (1941,S.), the method has already been tested in the field, was found satisfactory, and is being introduced into construction practice.

I Physico-Chemical Processes

A system of metallic rods, the electrodes, is forced into the ground. The application of current is followed by the electro-osmosis and a consequent dehydration of the ground. Aluminum and hydrogen ions replace, by the cation exchange mechanism, sodium and calcium (if so, Mg and other exchangeable bases should be likewise replaced - S.). Finally, the structure-forming processes are initiated, in consequence of the separation of aluminum hydroxide. In such manner, the effect of electro-osmosis is not only intensified by the exchange reactions but is also rendered stable (i.e. practically irreversible - S). This is confirmed by two year observations. It is well known that the degree of hydration of clay depends on the kind of exchangeable cations. Thus hydration and thickness of the water films of a sodium clay are always greater than that of a calcium clay; they are also greater for a calcium clay than for an aluminum clay. Thus, making use of aluminum electrodes and inducing exchange reactions whereby sodium and calcium are replaced by aluminum and hydrogen, we produce a

dehydration of the clay and a fixation of the total effect. Occurrence of the exchange reactions, in the course of the electrochemical stabilization, was proved by a number of experiments.

The first series of experiments consisted of determining exchangeable bases (Na,Ca,H, Al) in four natural kinds of clay, before and after stabilization. The results indicated that, in all four instances, exchangeable hydrogen has entered the complex in consequence of the stabilization and the proportion of exchangeable aluminum has increased. Concurrently, the proportion of exchangeable sodium decreased significantly and exchangeable calcium was somewhat diminished.

The second series of experiments, with two clays saturated previously by sodium, calcium and hydrogen, gave still more significant results. The effects were more pronounced (i.e. more Al entered the exchange complex - S.). The results showed, beyond doubt, that exchange reactions to take place during the electro-chemical stabilization.

Electro-osmosis, i.e., the movement of ground water to the cathode, was also studied.

The theory of the capillary water transfers, following application of different potentials, was studied first by Helmholtz in 1879. After the correction of Helmholtz's equation by Pellat 1/ in 1904 and the generalization of Perren 1/, the well-known equation for the electro-osmosis through a multi-capillary diaphragm had become, in the c.g.s. dimensions:

$$ U = \frac{\int D \nu E}{4 \pi \eta L}. \quad (1) $$

In electro-osmotic measurements in water or in weak aqueous solutions of electrolytes, in the presence of a diaphragm of a porous material,

D   is the dielectric constant of water, and equals 81.

E   is expressed in volts;

$\int$ the potential, is in millivolts;

U - in cm. 3/min.;

L - in cm.

    the total cross-section area of the capillars of the diaphragm, in cm^2;

Viscosity (i.e. η , the viscosity coefficient of water in equation 1.-S) is assumed to equal 0.01 poises.

The equation assumes then a simplified form,

$$ U = \frac{\int \nu E}{k L} \quad (2), \text{ where } k = 2355. $$

This equation is used in many instances for calculation of the potential. In the literature on the electro-osmosis examined by the author, the transfer of water or of any other liquid is considered under the following conditions:

(1) The porous body is a diaphragm separating anode from cathode.
(2) Properties of the diaphragm remain unchanged during the electro-osmosis.

Our work aimed at discovering regularities in the electro-osmosis, with the earth mass as a diaphragm between the electrodes. Physical and mechanical properties of this diaphragm are changing continuously with the passage of the electrical current, inasmuch as both water and ions of the inner Helmholtz layer, at the surface of clay particles, are removed in the process. For these reasons, in equation (2) E should be replaced by I x R and R expressed in the dimension of specific resistance and size of the diaphragm. The equation becomes:

$$U = \frac{\zeta I \rho}{k}$$ (3), where ρ is sp. resistance of the ground, in ohms.

Since, in the electro-osmosis, the amount of water remaining in the ground is diminishing continuously, it should be reasonable to suppose 1/that the velocity of electro-osmosis conforms to the equation $\frac{du}{dt} = kQ$, where Q is

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1/ Engineer A. M. Malyshev participated, together with the author, in the development of the method.

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quantity of water remaining in the ground and subject to the electro-osmosis. The above differential equation is solved easily, for the quantity of water separated during time I:

$$Q = Q_0 (1 - e^{-kt}).$$ (4)

where T is in minutes, Q_0 - the quantity of water subject to removal by the electro-osmosis $\in$ T $= \rho$, k - a constant which depends on magnitude of the ζ - potential of the clay and on the density of current.

The latter equation was verified in 12 experiments. The quantity of water transported, in the apparatus, to the cathode coincided entirely with the quantity calculated from equation (4).

The movement of water toward the cathode indicates an excess of negative charges in the inner Helmholtz layer of the investigated clays.

We have considered also, alongside the electro-osmosis and the chemical mechanism of the process, the water-stability of both stabilized and untreated samples. As to the cataphoresis, i.e. transfer of clay particles, toward the anode, as a consequence of the application of current, our experiments showed that the phenomenon has no place, in this particular case, within the ground mass. Water-stability of both stabilized and untreated samples was studied in two aspects; first, by determining the rate of disintegration in water, and

second, by determining the degree of swelling in water and in solutions of gelatine. The experiments, indicated that both natural clays and the clays pre-saturated with sodium or calcium do not disintegrate and cease to swell in consequence of their electrochemical stabilization.

Fig. I shows samples of a natural clay kept in water for $2\frac{1}{2}$ years after their stabilization by the current. Fig. 2 shows differences in swelling of stabilized and untreated samples in solutions of gelatine. Untreated samples, saturated by different cations, are in the upper row of the beakers (Fig.2); the stabilized samples are in the lower row. The greatest swelling is observed in untreated sodium clays, which is in harmony with the present day concept of the significance of the absorbing complex of clays in determining their behaviour in water. These same samples, however, lose their capacity to swell after their stabilization.

II Radius and Massiveness* of Stabilization

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*"Monolitnost" - "monolithic character", in the original. This noun, in Russian, has a broader usage than in English. My rendition of the term is not entirely fortunate - S.

A noticeable increase in density of the ground at the anode and a certain thinning at the cathode can be seen shortly after the application of the current. Later on, the cathode zone similarly gains in density. In such manner, in the majority of the cases, the fluid clayey ground is made dense in the vicinity of both electrodes. If the current is applied for a sufficiently long time, the entire mass between the electrodes may be rendered equally dense, in the majority of the cases.

Fig. 3 illustrates the dynamics of stabilization. The diagrams refer to the four clays whose physical and mechanical characteristics are given in Tables I and II.

Table I - Absorbed bases, in milliequivalents (per 100 g. -S), before experiment

Clay***	Hygr.H_2O %	Ca	Mg	Na	Fe	Al	$CaCO_3$*	Sum	Exchange Cap
Kudinovo, sandy	4.12	19.31	4.67	0.63	2.49	5.72	none	33.56	32.82
" "lard"- (= gumbo S)	5.90	21.94	4.26	0.56	5.29	6.45	"	40.34	38.50
Borovichi	4.26	11.03	5.33	5.63	2.84	3.88	"	24.02	28.71

*) The original has "expressed as Ca^{++}", which is nonsense. I have corrected this error. It is a standard practice to indicate presence or absence of lime in all cation exchange measurements. The item "none" cannot possibly refer to any other measurement - S.

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Table 2 - Mechanical Composition of Clays before Experiment (Robison's Method)
% Fraction

Clay	Sieve Analysis				(Sedimentation ? - S)				
	5-2 mm	2-1 mm	1-½ mm	½-¼ mm	0.25-0.05 mm	.05-.01 mm	.01-.005 mm	.005-.001 mm	.001 mm
Kudinovo, Sandy	-	0.15	0.22	0.13	3.19	4.20	37.56	18.18	36.37
" , "lard"	-	-	-	-	11.17	19.14	40.51	14.43	14.15
Borovichi	-	-	-	-	0.08	12.03	16.58	12.39	58.32
Tsaritsino	2.06	2.56	4.16	4.30	32.38	29.79	17.47	2.76	4.5?

Clay	Density	Volume Weight	Porosity	Plasticity Index
Kudinovo, Sandy	2.71	1.67	22.36	21.11
" "lard"	2.71	1.87	31.00	26.12
Borovichi	2.70**	1.74	35.36	15.32
Tsaritsino	2.72	1.84	32.58	3.32

**The original has "3.70" which is obviously an error. 2.70 is probably right - S.

***Clays are identified by adjectives derived from proper nouns, names of localities
where the clays were collected. It is impossible to surmise with complete
accuracy, the proper noun from an adjective so derived, because of certain pecul-
iarities of the highly inflected Russian language. For example, the adjective
"kudinovskaia" (fem.) could be equally correctly derived from Kudinovskoe,
Kudinovsk, Kudinovo, Kudinov, Kudino, and possibly others. The same applies
to the other two. Having no clue in the original, except for Tsaritsino,
I have made the best reasonable guess - S.

The curves (Fig. 3) indicate the depth of penetration of a special needle
(Wick type) at different distances from the electrodes. The curves represent
25, 50, 75, 100, and 200 hour effects of the current. Current densities selected
for the tests were such as to avoid heating of the ground.

It is evident from the diagrams that the effect of current of one and the
same density is far from being the same for different clays. For example, Borovichi
clay can be stabilized at a rapid rate and may become monolithic after 100 hours.
At the same period of time, stabilization of Kudinovo clay failed to give signifi-
cant results. This contrast leads us to the supposition that there exists certain
limits of applicability of the method which are determined by physico-chemical
properties of clays intended for the stabilization. We do not have as yet a
sufficient basis for establishing such limits. It is beyond any doubt, however,
that one of the indicators, in determining suitability of ground for the method,
will prove to be the character of the exchange complex and the degree of dispersion
of the ground.

As to the current density and the power expenditure, a certain regularity
("zakonomernost" = conformity to the law - S) can also be observed. The higher
the current density - the more rapid the stabilization. Experiments and calculation
prove, however, that, in the stabilization of fluid ground, current densities in
excess of 20 amp/m² develop considerable heat. In regards to the total power

expended, 1 m^3 of ground requires 30 to 200 KWH. This wide range of variation is explained by variation of properties of the ground. For example, even among the tested clays, the Borovichi required but a fraction of the power consumed by the other two.

The pressure of current required for production of the desired density of current depends on the ohmic resistance of the ground and on distance between the electrodes. Every meter distance between the electrodes requires, on the average, 100 to 200 v.

It follows, therefore, from the dynamics curves and from the relationship between density of current and effectiveness of stabilization, that power expended, per m^3, also depends on distance between the electrodes. Indeed, to obtain the same density of current between (two pairs of - S) the electrodes one meter and half a meter apart, about 100 V and about 200 V respectively should be required. If the density of current is the same in both cases, and if the increase of the bulk of stabilized material takes place at the same rate, a complete stabilization of the entire mass between the electrodes will take place sooner where the distance is shorter. (i.e. All other things being equal, the rate of stabilization is inversely proportional to distance between the electrodes - S). Hence, wherever the electrodes can be driven into the ground without much trouble, we should aim to minimize the distance. In such manner, the time and power expense would be reduced. If a close spacing of the electrodes is not feasible, they can be arranged at any desired distance from each other. The required power and time, in such case, shall be determined by the distance chosen.

The depth of stabilization depends entirely on power of the rig for forcing the electrodes into the ground. The silicate-treatment experience indicates a 20-25 meter depth.

III Raising the carrying strength of piles)
     ("svaia" = pile, bridge support - S)

One of the applications of the electro-chemical process may be, undoubtedly, an increase in the carrying strength of piles. As it can be seen in the diagrams, the stabilization at the anode, and in a number of cases at the cathode as well, begins shortly after the current is applied. If the piles are made to serve as the electrodes, the electric current may produce a stabilized pediment at the foot of every pile. On account of the appreciable cohesion between the ground so treated and the surface of piles, the carrying strength of the latter may be made to increase significantly. These considerations have led us to laboratory experiments with models. Aluminum piles, 40 cm. long and 34 mm in diameter were sunk into a thinned clayey ground (Tseritsino clay). Because of the insignificant bearing power of such ground, the piles were allowed to sink under their own weight. They were supported by special rods before the current was turned on. From then on, the carrying strength of piles was determined at regular intervals of time.

After a large number of tests, it became possible to establish a relationship between the carrying strength of piles and the expenditure of power. The ordinate

of Fig. 4 expresses the carrying strength in $g./cm^2$, and the abscissa - the expenditure of power in Wh/cm^2 pile surface. It may be seen that cohesion between the anode and the ground is greater than it is for the cathode and that the optimum for both electrodes is at 1.25 Wh/cm^2. A decrease in the carrying strength, following attainment of the maximum, should be related to cracking and to loosening of the pediment (due to progressive drying? - S)*

*In the course of our experiments an article by Casagrande appeared in "Die Bautechnik", No. 1, 1937, on increasing carrying strength of piles by the electrochemical process. His experiments in the field, with piles 8 m. long, yielded curves analogous to Fig. 4.

Our results show that a several-fold increase in the carrying strength of piles required a very small amount of electrical power. Wooden piles should be coated by metallic plates.

We have conducted also a large number of experiments with introduction of solutions of chemicals into the ground, in addition to the previously described experiments with the utilization of DC only. The introduction of chemicals was made feasible by the fact that, under the influence of electrical current, water moves from anode to cathode. In such manner, small amounts of solutions of chemicals can be introduced into an almost impervious ground. In the latter cases, in addition to the processes previously described, there occurs a separation of the cementing substance within pores of the ground. This is important, particularly where the exchange capacity is inadequate for the stabilization by DC only.

It is of interest to note that the stabilization progresses at a considerably higher rate in the presence of chemicals and leads to a cementation and to a mechanical firmness of the ground, as well as to a general increase in density. Fig. 5 is a photograph of a ground cemented in proximity to the rod, as seen after the rod was pulled out of the ground.

IV Stabilization in digging through "floater"
("plyvun" = "floater", a wet unstable clay - S)

The electrochemical process, as a means of stabilizing clayey ground, was tested in the field.

The clayey ground to be stabilized, a floater, had a very low exchange capacity and, accordingly, needed addition of chemicals, prior to the stabilization. For this reason, extensive preliminary studies were required to determine the composition of the best suited chemical mixture. After the recipe was compounded, the field experiment was begun.

The experimental plot was situated on the left bank of Iausa River in the region of Epipany Street (Preobrazhenie = Epiphany - S) In this area, construction of the Iausa collector drain was begun by the Moscow canalization Agency ("Mosstroikanalizátziia" - S) A shield-screen ("shpunt" in the original-S) was driven in, after the trench was sunk to 8 m. depth, which was the ground water level. Under the protection of this shield, a pit was being dug below the ground water level. It developed, however, that, on account of the low permeability of the ground and of the upward pressure of ground water, the clay was loosened and

acquired properties of a floater within a relatively short time. It became evident, before long, that, despite intense excavation, the pit cannot be sunk to the intended level. A kind of an equilibrium developed in the pit and no amount of excavation could lower the pit bottom below a certain mark. One of the pits was chosen for our experiment where it was required to excavate at 3.5 m. below ground water level.

To stabilize the entire ground mass enclosed within timbered walls of the pit, the electrodes were arranged as shown in Fig. 6. Such arrangement was conditioned by the necessity of increasing the density of ground in the entire cross section of the pit. Distance between the electrodes was about 1 m. and was defined by the characteristics of the circuit, 120 V pressure and 62 kW power. After 8 days, however, the work had to be discontinued because of the frequency of "no-current" periods ("prostoi") due to faulty connections ("montaj aggregata" = "assembley of the aggregate". My translation may be incorrect -S).

Further stabilization work was conducted with the utilization of the "electrosvarochnyi aggregat" (meaning unknown to me. See note to Table I, appendix to the first article. "Aggregate" may refer also to the circuit - S), yielding a maximum pressure of 60 V. For this reason, the original arrangements of the electrodes was altered. Distance between the electrodes was cut down to 50 cm. After the total power expense attained 62 kWh per m.[3], the stabilization was discontinued and the excavation was begun.

Probings with a metallic rod showed that the ground was not lithified but has merely increased in density significantly. It was proposed therefore to install a protective shield, for the sake of safety (lit. "to create a more quiet environment" - S) during the excavation and the collection of samples. Our attempts to force the shield into the stabilized ground did not succeed. The excavation was begun therefore without the protective shield and merely with a very light timbering of the walls, as the pit depth increased.

Digging through the floater, transformed, in consequence of the stabilization, into a very dense clayey mass, was quite easy. The ground was cut with a spade and, while slightly moist, was loaded into a bucket. As the depth increased, the upper section of the pit was timbered and the excavation continued.

As it may be seen in Fig. 7, the moisture content of the pit material was very low, which shows that thin walls of the stabilized material were practically impermeable to water. After the pit was dug to 8 m. below ground water level, i.e., to the end of the stabilized zone, a still deeper excavation was made impossible by the floater which, as a fluid highly hydrated mass, began to flood the pit.

Samples for laboratory tests were collected in the course of the excavation. Moisture-content of the stabilized ground was about 20% for the untreated - up to 53%.

Together with samples of the stabilized floater, samples of a well-cemented ground were taken in proximity to the electrodes. The radius of cementation was not great, 15-20 cm.

Comparison of different methods of stabilization. (Table 1 from Rzhanitzin, B.A., pp. 14-15, of the "Reports")

Method	Suitability	Stabilization Characteristics	Application	Material Kind	Material Quantity	Equipment	Cost (in roubles)
Silicate-treatment	Sandy ground; filt. coef. 2-80m./24hrs.	(1)Firmness; 15-60 Kg./cm^2 (2)Imperviousness	(1)Structure foundations (2)Protection of pits from ground water (3)Underground excavation	(1)Na$_2$SiO$_3$;mod. 2.6-3; Sp.gr 1.25-1.30. (2)CaCl$_2$; Sp. gr. 25-1.30	(1)200-400 L/m^3 (2)" " "	1)Pumps; pres. up to 30 qtm. (a)hydraulic press (b)type "E" (izhoretz) 2)"Serpents"** 3)Injectors; (4)Silicate cookers 5)Equipment for driving in and for withdrawing the injectors.	150-250 per m^3
Bitumen, cold	Sandy ground; filtr. coef. 10-100 m./24hrs.	(1)Imperviousness (2)Cohesiveness	(1)Screens and walls impervious to water. (2)Protection of pits from ground water	(1)Bitumen emulsion, 30-45%; particles .001 to .003mm. (2)CaCl$_2$ or complex ethers	(1)200-400 L/m.^{3} (2)1-2Kg. (per m32-S)	1)Pneumatic pumps***(2)"Serpents"** 3)Injectors (4)Equipment for driving in and for withdrawing the injectors	150-200 per m.^{3}
Electrochemical	Silty-clayey, clayey, and loess ground; filtr. coef. 1 m./24hrs.	(1)Increase in density (2)Water-stability	(1)Increase of bearing strength of piles and foundations. (2)Construction in fluid ground (3)Control of landslides and ground swells.	(1)Direct current (2)CaCl$_2$, Na$_3$PO$_4$, other salts	(1)200-100 kWh/m^3 (2)10-40Kg. (per m32-S)	1)****) (2)Electrodes(iron) (3)"Serpents"** and hydraulic presses	10-50 per m^3
Cementation	Fractured rock; cracks 0.15mm.	(1)Monolithic structure (2)Imperviousness	(1)Impervious screens in hydrotechics (2)Mining in water-bearing strata (3)Filling of cavities in shafts and tunnels.	Cement, not lower than "400" grade	Varies within wide range	(1)Drills or perforators (2)Cement pump (3)Mixers (4)Pipes	Drilling: 50-100 per m.* Cementation: 50-100
Clay-treatment	Cavernous cracked rock with a weak flow of ground water	Imperviousness	Shafts and underground works	(1)Clay suspension sp.gr. 1.20-1.45 (2)CaCl$_2$ or lime	(1)Varies within wide range (2)5-10% of clay suspension	(1)Drilling equipment (2)High pressure cement pumps (3)Clay mixers (4)Pipe conduits	Drilling: 50-100 per m. Clay-treatment: 10-50
Bitumen, hot	Fractured and cavernous rock	Imperviousness	(1)Protection of pits from underground water (2)Water-impermeable screens in hydrotechics	Bitumen "III" or "IV" grade	50-200Kg. per m.*)	(1)Drilling equipment (2)Pumps with pres. up to 30 qtm. (3)Boiler for heating bitumen (4)Drill-hole armature, with electric heaters	Drilling: 50-100; Bitumen treatment: 15-60
Freezing	Water-sat. ground and rock	Temporary stability and imperviousness	Underground excavations and pits	(1)CaCl$_2$ (2)NH$_3$	————	(1)Drilling equipment (2)Freezing plant (3)Drill-hole armature	100 per m.^{3}

Translator's notes:
*)"pogónnyi metr", I think, refers to one meter either depth, length, or height; other dimensions variable.-S.
**)"Serpents" is probably hose, tubing, or flexible pipes; the original uses "Schlange", a German term, although there are Russian equivalents of "schlange".
***)"nagnetátel" may mean a pump working in reverse, to force liquid into soil; Rus. for "pump" is "nasós".
****)"Electrosvárochnyi aggregat" is "aggregate suited for electrical cooking (or blending?)" or "electrically cooked aggregate". The meaning is obscure to me.-S.

fig. 1. Photograph. 3 tumblers with slabs of clay immersed in water. 2½ year immersion. Stabilized samples. No sloughing-off in No. 215; some disintegration in No. 66; a visible disintegration ½ in No. 365. Clays not identified, except by number. Poorly printed photograph.

fig. 2. Photograph. 10 tumblers, in rows of 5. Ca and Na clays, in the upper row, disintegrated in aq. gelatine, with Ca-clays retaining traces of their original structure. Lower row: comparable to the upper; stabilized Na and Ca clays. No visible disintegration.

fig. 3 — separate sheet.

fig. 4.

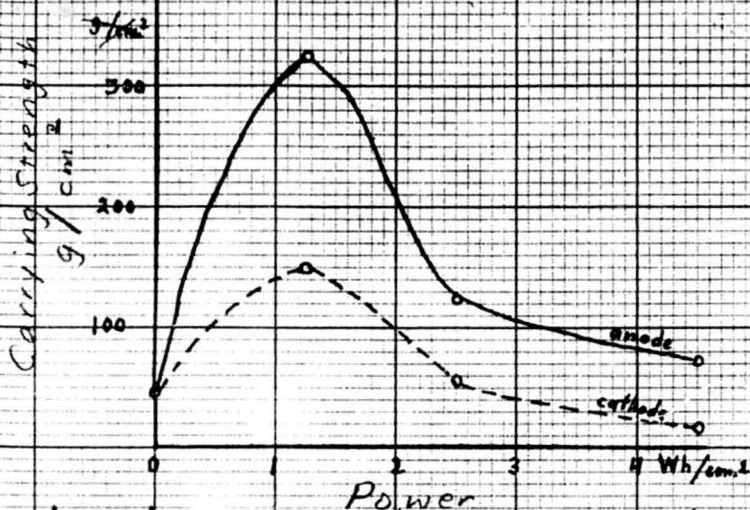Relationship between carrying capacity of piles and energy required for stabilization of adjoining ground

fig. 5 A seemingly monolithic, roughly heart-shaped clod, 2¼" long and 2" to ¾" wide adhering to a rod 1/16" diam (measured on the photograph).
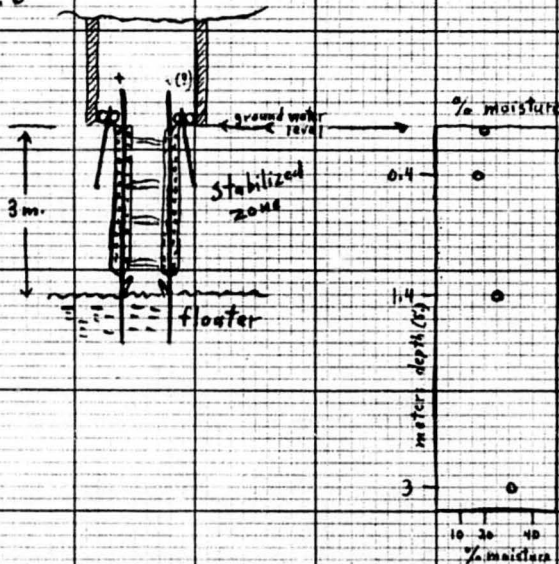
fig. 6

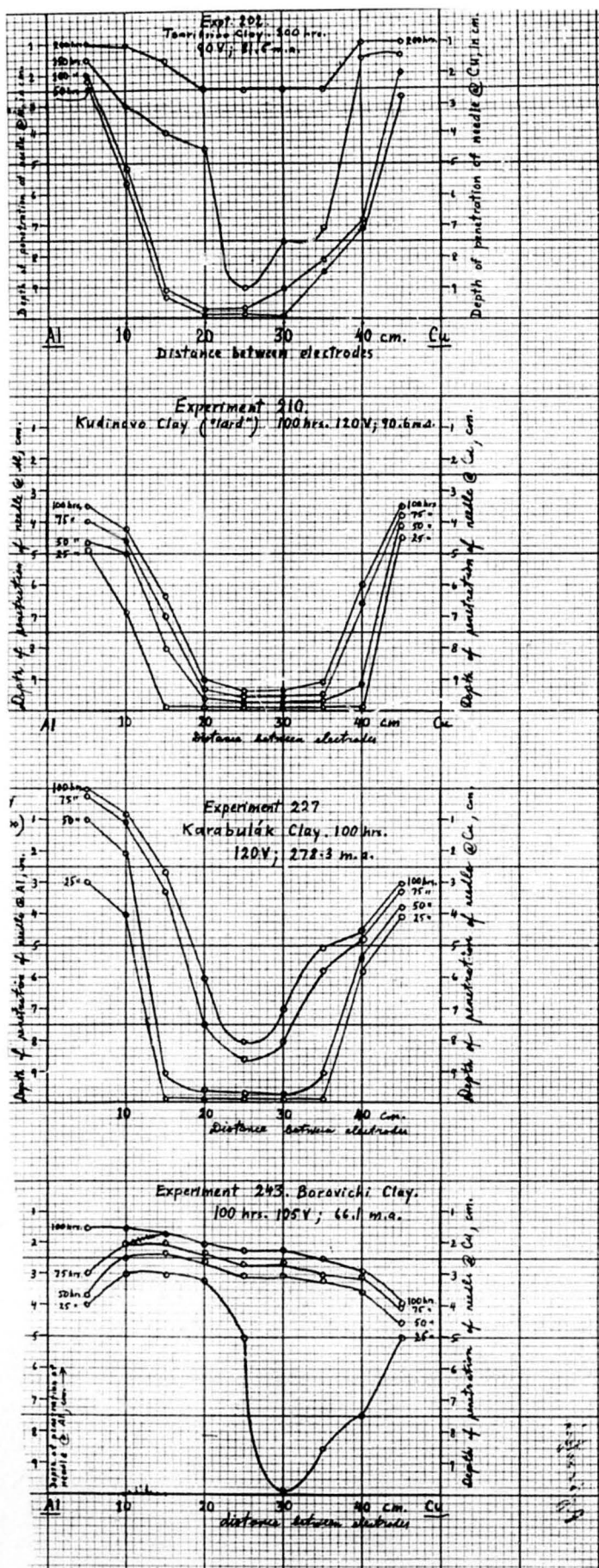

fig. 7 An amorphous cohesive earth mass, with spade ⅔ in.

Figure 3. Dynamics of Stabilization of Ground

(Rzhanitzin)