Electrochemical Stabilization as Means of Preventing Ground Failure in Railroads

by

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Translated from the Russian
by
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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 as Means of Preventing Ground Failure in Railroads"*)

Translated from the Russian by V. P. Sokoloff, U. S. Geological Survey
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Solntzev, D. I., and V. S. Sorkov (Nauchno - issleaovatelskii Institut Puti i Stroitelstva NKPS). (Research Institute of Communications and Construction, Peoples' Commissariat of Communications). "Elektrohimicheskoe Zakreplenie Gruntov dlia Borby S Puchinami na Zheleznodorozhnom Transporte". Akademiia Nauk SSSR. (Academy of Sciences USSR). Soveschanie po Zakrepleniiu Gruntov i Gornyh Porod (Conference on Stabilization of Ground and Rock). I Doklady (I. Reports). Moskva (Moskow). 1941. 167 pp. Pages 67 to 79.

*) "ground failures" is used as an equivalent of "puchina". Puchina, a noun, has the following connotations:

(1) der Abgrund, "abyss", depth;
(2) Schwellen, guellen, aufbauschen, in die Hohe treiben, to swell, to rise, to surge.

Not knowing the exact English term for puchina, I have rendered it as "ground failure".

"Zheleznodórozhnyi Tránsport" = "Railway Transportation" is used idiomatically in the original, to include both the system of railway communications and the condition of road beds. I have translated this expression as "Railroads", which is inadequate but at least brief.

"dlía borbý" = "to combat", I rendered as "means of preventing", to avoid what would appear a rather bizarre concatenation of terms, were I to prefer literalness to sense.

Note: The term "soil", póchva, is avoided in the original. "Ground", grunt, (pron. groont) is used consistently. The translator is obliged, therefore, to use "ground" in many places where "soil" would be a better fitting term. S.

The majority of grounds in their fluid (or plastic - S) state have a low bearing strength which is inadequate for the support of private and industrial constructions. It is reasonable therefore for the investigators to search and to develop processes and methods whereby the low bearing strength could be increased and the physico-mechanical properties of grounds altered, to render the ground well-suited for construction.

Clayey ground, in its fluid state, is practically devoid of bearing strength. Clays cannot be stabilized by methods adapted to sandy soils or sands, on account of their low permeability to water and of the small size of the pores. Attempts in such direction had given negative results.

A recently developed electrochemical process of stabilization of clayey ground permits substantially to increase the bearing strength of liquid clays and silts and to inhibit their subsequent softening and swelling.

The electrochemical process consists of forcing a network of metallic rods into the ground to be stabilized; the metallic rods are later used as the electrodes; following the passage of direct electrical current, the ground becomes more dense and loses, for the future, its capacity to soften and to swell. The physico-chemical processes induced by the current are responsible for the change. With these considerations in mind, the NIIPS NIIPS (Research Institute of Communications - S) had organized, in 1939, experiments to ascertain suitability of the electrochemical method for the prevention of ground failures in roadbeds of railways. -1/

1/ In consultation with Professor B. A. Rzhanitzin (the author of the preceding article - S)

Two types of problems were indicated in this connection:

(1) Laboratory studies, with and without addition of chemicals or salts.
(2) Experiments in the freezing laboratory, to determine the swelling properties of the stabilized ground.
(3) Field experiments.

I Stabilization of Swelling Ground in the Laboratory

1. Kinds of Ground.

No. 1 (from earth bed of a railroad.) Light weakly carbonate morainic clay loam with a large proportion of sand, gravel, and other coarse materials; varies greatly in its mechanical composition, (Table 1); the high proportion of particles smaller than 0.001 mm (1 colloidal clay - S) is conspicuous; chiefly Ca - saturated (table 2).

No. 2 (from earth bed of a railroad). Darker than No. 1, heavier-textured; with a large amount of humus; few coarse materials (locally, weathered boulders); chiefly Ca-saturated (Table 2); the 0.001 mm. fraction prominent, as in No. 1; removal of carbonate causes a striking increase in the proportion of 0.001 mm particles; No. 2 becomes, in such manner, a dusty (deflocculated - S) clay.

No. 3 (collected at Tzaritzino Station, near Moscow); contains much silt (79.64%) and is classified as a heavy, silty sandy loam; contains absorbed sodium (table 2).

Table 1. Mechanical composition of original samples. Percent.

No.	10mm.	10-5 mm.	5-3 mm.	3-1 mm.	1-0.5 mm.	.5-.25 mm.	.25-.10 mm.	.1-.05 mm.	0.05-.01 mm.	0.01-.005 mm.	.005-.001 mm.	.001 mm.
1	1.87	3.95	2.52	8.80	5.62	14.58	15.80	8.53	11.77	14.40	2.80	9.36
2	1.07	0.06	0.12	1.28	2.76	11.25	4.88	6.56	24.08	28.52	1.10	18.32
3	--	--	2.06	2/56	4.16	4.30	32.38	--	29.78	17.47	2.76	4.5[illegible]

Table 2. Physico-chemical characteristics

No.	Sp.gr.	Vol.Wt.	Porosity	% Hygr. Water	Atterberg Constants L.L.%	Atterberg Constants R.o.L.%	Atterberg Constants P.I.%	Swelling %vol.incr.	Terzaghi coef. of filtr. 1 kg./cm.²/m./24 hrs.	pH	Exch. Capacity, Bobko-Askinazi, m.e./100g.
1	2.88	1.34	53.47	5.36	42.0	23.63	18.37	45.0	0.0015	6.4	20.17
2	2.66	1.33	50.00	5.85	72.68	25.31	47.37	113.0	0.00031	6.6	42.01
3	2.72	1.84	32.36	2.82	25.85	17.03	8.82	39.00	----	---	---

No.	Exchangeable bases, m. e./100 g. Ca^{++}	Mg^{++}	K^{+}	Na^{+}	Fe^{+++}	Al^{+++}	Sum
1	21.16	2.85	0.18	2-3	3.06	0.0	29.25
2	39.73	4.18	2.51	4-5	2.06	0.0	52.48
3	4.61	2.69	--	6.18	3.05	5.45	21.98

2. Laboratory Methods

3 mm. sieve was used for screening the samples. Electro-chemical stabilization was generally undertaken at moisture-content approaching the liquid limit, and, in some cases, above the liquid limit. Experiments were conducted in glass-lined wooden boxes 50 x 10 x 5 cm. Some experiments were made in cardboard cylinders. Direct current of 110-125 V. was used.

Effects of higher current densities were studied in special tests. 5 x 10 cm plates of copper (cathode) and of aluminum (anode), in parallel positions, constituted the electrodes. Experiments were made also with iron anodes.

Stabilized ground was tested for stability by soaking in water, without agitation. Disintegration (i.e. sloughing-off. S.) was expressed tentatively in percent, so as to make possible drawing of the soaking curves. 100% disintegration was taken to be the time when the tested clod would either lose its cohesion entirely, falling into its smallest constituents, or would slump and loosen completely, without retaining any semblance of form or aggregation

The Atterberg constants and swelling in water were determined, to ascertain the effect of DC on plasticity of the ground. The swelling was measured by a somewhat modified Filatov method, in graduated cylinders 10-12 cm. in diameter. pH was determined by the Michaelis method.

Changes in permeability of the stabilized ground (anode, cathode) were defined by the filtration coefficients of Terzaghi.

Increases in density (as a criterion of the bearing strength.-S.) in the process of stabilization were determined by the stamp-device (a kind of a penetrometer ? -S.), operating according to the principles of Wick's*) Needle

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*) The Russians, as a rule, transliterate foreign names with only an occasional regard to the spelling or the sound of the original language. Thus "Vick" could be Vik, Vick, Vyk, Wyk, Wyck, etc., etc. This name is not cited in the available bibliography and, therefore, my tranliteration is uncertain. S.

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3. Electrochemical stabilization in the absence of added chemicals.

Changes in density of the gr und, as measured by Wick's needle, and behaviour of stabilized ground in the presence of water were the two fundamental criteria of the effectiveness of stabilization. Studies of the physico-chemical and chemical processes taking place during the stabilization were conducted at the Institute of Communications, by the Chair of Soil Science MGU (B. V. Tolstopiatov).

A significant lowering of the moisture-content in stabilized ground was shown in experiments illustrated by figures 1-3. Near the anode and the cathodes (except.4) this lowering was almost 50%. Experiments in the absence of added chemicals also show a lowering of both the liquid limit and the plasticity index. The lowering of the plasticity index is especially conspicuous in expts. 85 and 8 (fig. 2, 3). Swelling is diminished at both anode and cathode. pH of the stabilized ground increases regularly from anode to cathode (from 3.2 to 7.6), being intermediate in the middle part of the sample. All stabilized samples were tested for stability by soaking in water. The results showed that the anode and the cathode zones were the most stable ones. Middle portions of the sample, between the electrodes, gave somewhat less satisfactory results, although the effect of DC was manifest even there.

The penetrometer* tests indicated sifnificant increases in density both in the anode and the cathode zones; the increases were somewhat less significant between the electrodes.

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*The original has "stamp", meaning the Vick's needle. - S.

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4. Electrochemical stabilization with addition of salts.
(a) Calcium chloride.

These experiments, as well as the former ones, without the addition of salts, showed decreases in moisture-content, swelling, and plasticity. pH trends were likewise similar: 3.4 to 4.4 at the anode, gradually increasing to 7.4 at the cathode. Stability in water indicated improved qualities of the ground, particularly in the cathode zone, as compared with the ground stabilized without the addition of chemicals.

Effect of the variation in current density (from 2 to 9 milliamperes per $cm.^2$ cross-section) on the stabilization was studied in ground No. 2, with the addition of 2% $CaCl_2$. Current pressure was maintained at about 120 V. The strength of current was determined by the indicated current density. Duration of the experiment was 93 hours. The ground became heated, in the course of the experiment, to varying extent. Thus, in expts. 44 and 45 (density 2.3 $m.a./cm.^2$) there was no apprreciable heating of the ground. In expts. 46, 47 (4.5 $m.a./cm.^2$) there was a slight heating effect ($30^{\circ}C.$). In expts. 48, 49 (6.7 $m.a./cm.^2$) the heating was marked ($60^{\circ}C.$); Intense heating of the ground (up to $80^{\circ}C$) was observed in expts. 50, 51 (8.9 $m.a./cm.^2$).

Determinations of the filtration coefficients of stabilized ground, in this group of the experiments, merit our attention (fig. 5). The filtration coefficient of the anode was higher than for the untreated ground, tending further to increase with the increase in current density. The cathode zone, on the contrary, showed 1.5 to 2 times as low a permeability (as the untreated.-S.). The increase of the filtration coefficient at the anode should be explained by changes in the micro-structure under the influence of the current. One should consider the preponderance of exchangeable H^+ and Ca^{++} at the anode, in this connection.-S). The lowering of the filtration coefficient at the cathode, following the increase in current density, is explained apparently as a result of the cataphoretic phenomena in the course of the stabilization (Rzhanitzin reports absence of cataphoresis in comparable conditions.-S).

In considering the soaking tests of this series, (fig. 6,7), it may be seen that the properties of the cathode zone had consistently improved and that the ground had become water-resistant, for all practical purposes. A peculiar ladder-like relationship is indicated for the anode zone. Thus, in expts. 44, 45, the ground disintegrates (in water) very slightly; in expts. 46, 47 give unfavorable results; expts. 48, 49 show practically no disintegration; expts. 50, 51 give again unfavorable results.

(b) Sodium salts.

The series consists of three experiments with ground No. 1: expt. 42, with addition of 2% sodium phosphate (tertiary?-S); expt. 43, with addition of 2% sodium phosphate and 0.1% of phosphoric acid (percentages of the weight of sample used.-S); expt. 32, with addition of 1% sodium chloride.

The series is characterized by a higher moisture-content of the ground stabilized in the presence of the phosphates of sodium, in comparison with ground stabilized without the addition of chemicals. Liquid limit and Plasticity Index are also increased, even in comparison with the untreated sample. Swelling was diminished in the anode zone but rose abruptly at the cathode, in comparison with the untreated sample. Swelling was diminished in the anode zone but rose abruptly at the cathode, in comparison with the untreated ground, - an almost five-fold increase (fig. 8 & 9). pH trends are regular, as in the preceeding tests, increasing toward the cathode. Filtration coefficients (expt. 43) of the stabilized ground appear the same as in the previously described tests with the addition of chemicals, i.e. the filtration coefficient is higher for the anode than for the cathode zone.

The water-stability (soaking) tests indicate a fair stability of the anode and of the inter-electrode zones; the cathode zone disintegrates within a few hours. The behaviour of the cathode zone is explained by unfavorable effects of sodium ion and of sodium compounds. Other properties of the ground (moisture content, swelling, plasticity) are in line with this explanation.

We conclude, by way of a summary, that the entire complex of properties of stabilized grounds can be arranged in the following descending series: the best indicators are given by grounds stabilized in the presence of $CaCl_2$; the next best are for the grounds stabilized without any chemicals; the poorest ones belong to the grounds stabilized with the addition of sodium salts.

5. Studies in the freezing laboratory

Ground failures in railroad beds are quite injurious to the transportation. There exists a number of ways to guard against such failures. The most suitable method in practice is insulation (slag and other types of covering). These methods however, require reduction in train speed and even a stoppage of train movement.

The electrochemical process requires no interruption of traffic and is technologically simple. The method therefore, as the means of preventing ground failures, appears to be particularly interesting.

In addition to the previously described studies, we have worked with the swelling properties of stabilized grounds in the freezing laboratory and in the field.

The work in the freezing laboratory consisted of two parts:
(1) Studies of the migration of moisture in stabilized ground, as a factor directly related to the ground failures.

(2) Studies of swelling properties of stabilized ground.

(a) Migration of moisture

Ground was stabilized in cardboard cylinders 25 cm. in height and 10 cm. in diameter. The cylinder bottoms were perforated, to connect them with the source of moisture and to permit the upward rise of moisture (by capillarity.-S.). Filter paper was placed over the bottom of the cylinders. A metallic screen, with 1 $mm.^2$ openings was placed over the filter paper. This screen was loaded over the screen. The moisture-content of the sample was close to the liquid limit. The anode was an aluminum disc (placed on top of the sample.-S). At the conclusion of the stabilization, the aluminum disc was removed and the exposed top of the sample was covered by quartz sand, to minimize the evaporation of moisture. The cylinder, after such treatment, was ready for testing in the freezing laboratory. Cylinders loaded with untreated samples served as controls. Cylinders with stabilized ground and the controls were placed on top of filter paper over water-saturated sand, in a bath. Both cylinders and the bath were placed then into a wooden box, on top of a 35-40 cm. layer of ground cork (to prevent freezing from below). The space between the cylinders and the box walls was likewise filled with ground cork and only the topmost part of the cylinders remained exposed.

Thermometers were placed inside samples, at 2/3 depth (counting from top downward). Temperature at this depth was maintained, with fluctuations, between 0°C and -0.5°C.

Five series of experiments were conducted with ground No. 1

1st ------ 24 hrs.' freezing
2nd ------ 72 " "
3rd ------284 " "
4th ------336 " "
5th ------672 " "

Every series contained unstabilized ground (control), ground stabilized without chemicals, and ground stabilized with the addition of 2% calcium chloride.

At the end of the experiment, the cylinders were cut open at the joint and samples were taken for determinations of moisture: near top, in the middle, and at the bottom of the column. The last series (672 hours' freezing.-S) was also tested for stability in water, swelling, and plasticity, to ascertain the influence of the low temperature on the stabilization.

Untreated controls and samples stabilized without $CaCl_2$ (the original has "chemicals".-S) have developed horizontal layers of ice, up to 3 mm. thick, in the lower third of the column. Such layers of ice were observed in all the series. Their number and thickness varied with the time of exposure to freezing temperatures. In samples stabilized without $CaCl_2$, in addition to the horizontal layers of ice, other layers, at a certain angle to the former, were noted. In samples stabilized in the presence of $CaCl_2$, the ice developed only in the form of small individual lenses in the lower third of the column and in the form of a very small number of layers, 1-2 mm. thick, at 70°-80° angle to the bottom of the cylinder. These latter would extend, in places, to the middle of the column, corresponding to the complete (and thorough) freezing of the latter in the 5th series. (Meaning of the original is obscure.. The authors ought to have had untreated controls containing 2% $CaCl_2$ only. In the absence of such controls, their comparison of the 2% $CaCl_2$ columns with the untreated is not valid.-S)

Table 3, summarizing the determinations of moisture, illustrates the character of the upward migration of water. A definite relationship is indicated between the duration of freezing and the moisture-content. The most abrupt increase in moisture is shown in the column stabilized without $CaCl_2$. The untreated controls are next. The least change is in the column stabilized in the presence of $CaCl_2$. These trends correspond also to the swelling tendencies which will be discussed later.

(It is difficult for me to see the advantage of reporting more than three significant figures here and elsewhere. The determinations themselves are accurate, unless most expensive super-precision methods are used, only within the first three significant figures. Two significant figures are good enough for the interpretation -S.)

(b) Swelling

Stabilization methods and preparation of samples for freezing were the same in the migration of moisture studies. Treatment consisted of alternating freezing and thawing.

A "swellmeter" (puchinomer) was installed on top of the column (no sand covering was used), to register the extent of swelling. The instrument readings were recorded daily on the scale. Temperature was the same as in the moisture migration studies. Temperature was measured by thermometers, at 2/3 depth of the column. Experiments were conducted with ground No. 1. There were 8 cylinders in the series 2 of them contained ground stabilized without chemicals; 2 - ground stabilized in the presence of 2% $CaCl_2$; 2 - ground stabilized in the presence of 2% NaCl and $CaCl_2$. controls, without the applications of electrical current. The only valid comparison in this series is between the untreated and the DC - stabilized (without chemicals) samples.-S.).

The experiment lasted 912 hours. The columns were at negative (below 0°C.-S.) temperature for about 600 hours. The remainder of the time was at positive temperatures (above 0°C), in the alternating freezing and thawing. At the end of the experiment (after 912 hrs), the cylinders were cut open at the joint and samples were taken for analysis from top, middle, and bottom of every column. Moisture-content, swelling, stability in water, and plasticity were determined. The ice layers were of the same kind as in the water migration studies. The same characteristics were noted as previously: the absence of horizontal layers of ice in the columns stabilized in the presence of chemicals, and the presence of but a small number of almost vertical layers. Moisture-content of the loads before the stabilization was 44-45%; moisture-content of stabilized ground ranged from 31 to 35%, increasing from anode toward cathode.

The swelling properties of the investigated materials offer considerable interest. While the untreated ground swelled to the extent of 13 mm., the ground stabilized in the presence of chemicals showed practically no swelling, (fig. 10).

(If the depth of columns was 25 cm., as implied earlier in the text, if the "swell-meter" records only the vertical expansion, if there is no swelling in other directions, the maximum swelling was 5.2%., as against 0.60% and 0.14% for the other s.-S.). This can be hardly explained by the freezing point-lowering, due to the salts, as a thorough freezing of the mass could be observed toward the end of the experiment.

Explanation of the differences in swelling is in the character of the layers of ice. Intensive swelling takes place in columns developing growing horizontal layers (unstabilized ground). Where the horizontal layers are absent, there should be no swelling. Vertical layers of ice cannot push the ground upward (ground stabilized in the presence of added salts).

Durability of electrochemical stabilization

The aim of our investigation was to observe effects of the following agents on the stabilized ground:

(1) Tap water (soaking tests);
(2) Nascent carbonic acid (soaking in CO_2 - saturated water);
(3) NaCl solutions; it was of interest to follow through the possibility of exchange reactions and of the undesirable effect of sodium ion (soaking in 1N NaCl)
(4) Alternating drying and wetting
(5) Increased temperatures. Same as 4, except that drying, to a practically constant weight, was carried out in an oven at 50°-60°C.
(6) Alternating freezing and thawing. Same samples were used that were used in the freezing laboratory studies.

Soaking tests with stabilized ground No. 3 indicate that the ground behaves differently in different solutions. Disintegration in CO_2-saturated water is generally retarded for samples stabilized in the presence of $CaCl_2$ or stabilized without salts. Possible reasons for this may be sought in secondary chemical reactions between the CO_3 anion and, chiefly, the cathode zone of the stabilized sample, (in a CO_2-saturated water there is very little CO_3^{--} but, relatively speaking, a lot of HCO_3^-. Dissociation constant for the first hydrogen of H_2CO_3 is 3.5×10^{-7}; for the second hydrogen 4.4×10^{-12}.-S.) accompanied by formation of cementing precipitates in the form of carbonates of calcium and magnesium. Alternating air-drying and wetting of stabilized ground indicates a deterioration of water-resisting properties of the anode zone stabilized without addition of chemicals. The cathode zone and the intermediate, on the contrary, show a certain improvement. Ground stabilized in the presence of salts shows a marked improvement in all zones, after alternating drying and wetting. This is especially apparent on application of a higher drying temperature (50°-60°C.). Following the latter, ground stabilized either with or without the salts, changes its behaviour in the presence of water and becomes water-resistant ("unsoakable"), for all practical purposes. On consideration of changes in the properties of stabilized ground, following its gradual drying and a subsequent wetting, lead us to regard a certain amount of drying is beneficial. Such drying, apparently, brings about some irreversible changes in the colloidal system of the ground (which was modified by the

Table 3. Migration of moisture (moisture-content of samples after freezing).

Duration of expt., hours	Untreated			Stabilized without $CaCl_2$			Stabilized with 2% $CaCl_2$		
	Top (anode)	Middle	Bottom (cathode)	Top (anode)	Middle	Bottom (cathode)	Top (anode)	Middle	Bottom (cathode)
24	44.11	45.43	45.52	29.47	29.28	31.62	33.39	34.61	37.00
72	42.30	45.68	-----	29.25	31.95	33.53	33.56	35.45	-----
284	41.93	46.98	46.57	30.74	32.73	38.56	34.45	35.73	49.18
336	40.36	-----	61.41	-----	-----	51.38	30.05	35.85	53.86
672	40.65	44.37	41.03	29.96	30.74	35.[illegible]	31.64	34.34	36.87

processes induced by the electrical current), rendering it more stable in the presence of water.

Swelling of stabilized ground is diminished markedly (fig. 11, 12) after freezing, in all instances. Plasticity index tends also to decrease, particularly for the anode zone.

II. Stabilization in the field

A plot was selected, for experimental purposes, on a certain railway line where the frost heave (the original has "swelling humps".-S.) reaches 37 cm. height in certain years.

Stabilization was conducted in a timbered pit*). The bottom of the pit lies

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*) The Rus. term is "Kotlovan". The German equivalent of Kotlovan is Pfahlezaun für den Brückenpfeiler. My choice of "timbered pit" for "Katlovan" may not be altogether fortunate.-S.

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at the same level as the railroad bed. The kind of ground in the pit and in the earth bed of the railroad is identical. Swelling of the bottom of the pit is even somewhat more pronounced than swelling of the railroad bed developing at the same time, according to observations of the Ground Failure Station ("swelling station", "puchinnaia stantsiia", in the original.-S.). A reddish yellow clayey ... inic soil occupies the bottom of the pit. The soil grades, at 1 meter depth, into a highly ferruginized clay loam ("ironstone"), densely and firmly cemented, apparently by iron compounds, which constitutes the bottom*) of the first water-

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*) The Rus. term is "vodcupor", a compound noun meaning an obstacle to downward water movement. I do not know its English or German equivalent.-S.)

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bearing horizon.

Stabilization was conducted as follows. The bottom of the pit was divided into four sections. The first section was stabilized in the presence of 0.5% added NaCl; the 2nd - without chemicals; the 3rd remained untreated; the 4th was stabilized in the presence of 0.2% $CaCl_2$.

Iron rods and pipes, the electrodes, were arranged chess-board fashion.

The entire plot was watered abundantly for 2 days, before the electrodes were driven in. Sections entended for the addition of chemicals were impregnated with appropriate solutions. In the course of the work, the Sections were watered 5-6 times a day. Moreover, the anodes were perforated pipes into which were poured the appropriate solutions. Thus the electro-osmosis was employed to introduce salt into the ground.

The degree of stabilization was judged by the penetrometer ("stamp" in the original.-S) tests. Definite results could be obtained down to 0.75 meter depth. The electrodes were pulled out, after the experiment, by a gravity device*), [illegible]

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*) "Vega" in the original. I do not know the exact meaning of this term. Its German equivalents are die Schwere, Last, das Gewicht.-S.

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striking the top end of the rod. Without this aid the electrodes, particularly the anodes, could not be removed. The removed electrodes showed a certain amount change. The anodes were corroded severely, especially in sections with the ... The negative poles were practically unaffected. Determinations of moisture, ...ling, and plasticity indicated significant changes, in comparison with the ...ated ground; pH increased regularly towards the cathode; filtration coeffi... were altered markedly for the stabilized ground. These changes are in accord ... the results of the laboratory studies.

Soaking tests of samples from the $CaCl_2$ section yielded good results. There ... practically no change in the course of 500 days in a clod under water (fig. 13).

Data available up to February 1940 confirm the freezing laboratory results. ...ples from lower than ground with the addition of $CaCl_2$, and particularly of ...Cl, (from sections 1and 4), swells to a lesser extent than ground from the second ... third sections (fig. 14).

III. General conclusions

(1) The electrochemical method of stabilization is a new method of improving physico-chemical and mechanical properties of the ground by the means of direct electrical current.

(2) Processes caused by the current improve water-stability as well as mechanical properties of the ground. The resulting stabilization is not the same for all zones. The best results were observed in zones in proximity to the electrodes

(3). Effectiveness of stabilization depends largely on the kind of ground and on the addition of salts.

(4) Addition of calcium chloride gives the best results

(5) Addition of sodium chloride cannot be recommended, in the application of the electrochemical method, on account of an unfavorable effect of the highly hydrated sodium ion in the cathode zone.

(6) The use of iron anodes, in place of aluminum, may be recommended, for economic reasons, although they give slightly inferior results.

(7) Moisture movement studies in the freezing laboratory showed differences between stabilized and untreated ground. The movement of moisture was retarded in the former.

(8) Studies of ground swelling, in the freezing laboratory, indicated a diminished swelling in grounds stabilized in the presence of added $CaCl_2$, and particularly NaCl.

(9). Results of field tests are in harmony with the laboratory findings.

(10). Preliminary economic reasons allow us to consider suitability of the electro-chemical method for economic use in a number of cases.

(11) The power plant required for the electrochemical stabilization should include the following:

A DC generator, free from short circuits;
Current pressure 120-140 V;
Power 20-30 KW.

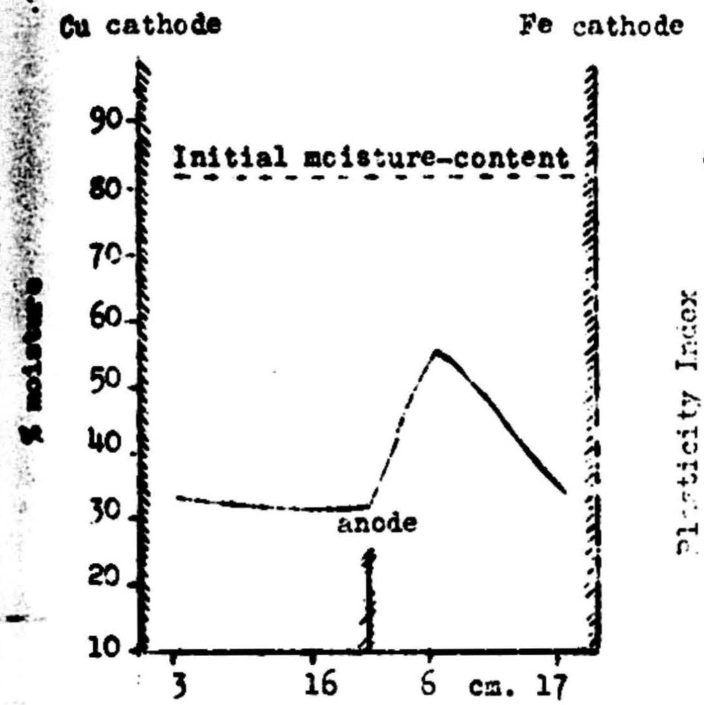


Fig. 1. GROUND WITHOUT CHEMICALS

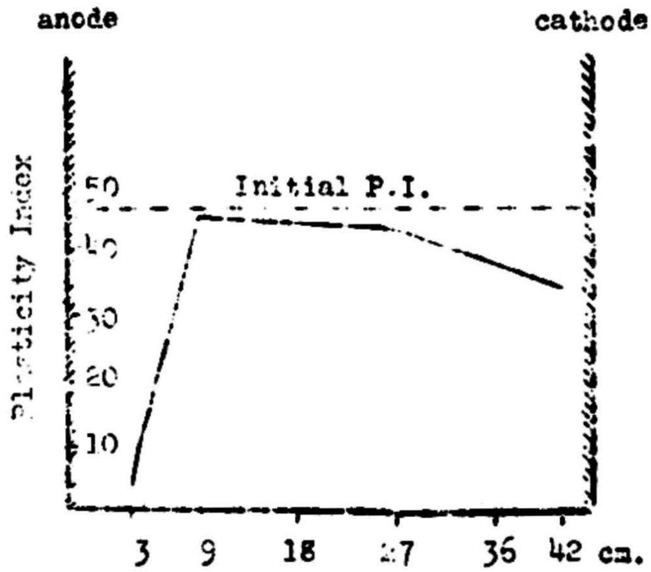


Fig. 2. CHANGES IN PLASTICITY

(Vertical scale exaggerated. In the original the lines are close together. - S.)

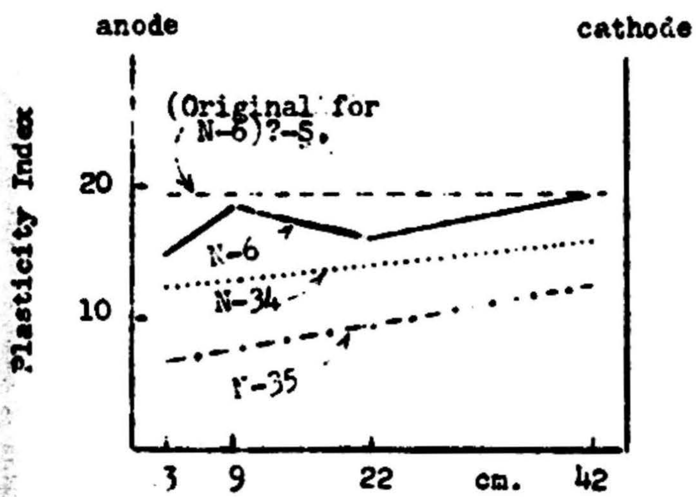
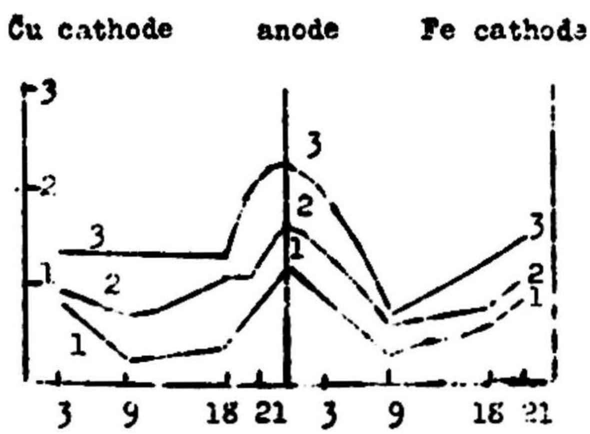


Fig.3. CHANGES IN PLASTICITY

(The ordinate may be the volume weight or some function of it. - S.)



Ground without chemicals:
1 - after 25 hours.
2 - after 50 hours.
3 - after 100 hours.

Fig. 4. INCREASE IN DENSITY ON STABILIZATION

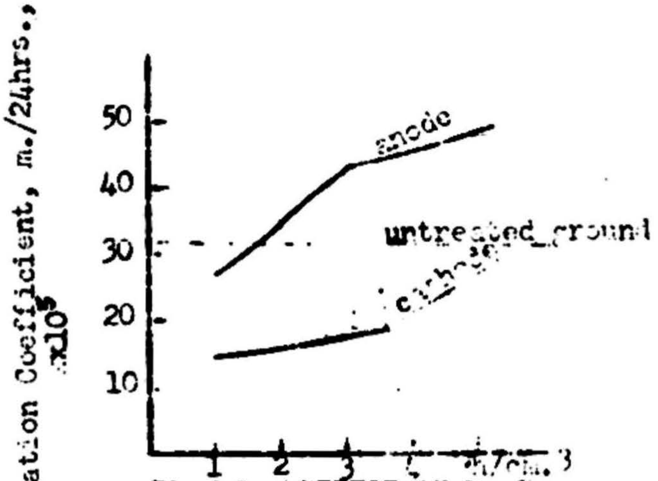


Fig. 5. EFFECT OF POWER EXPENDED ON FILTRATION COEFFICIENT.
(Title supplied by S.)

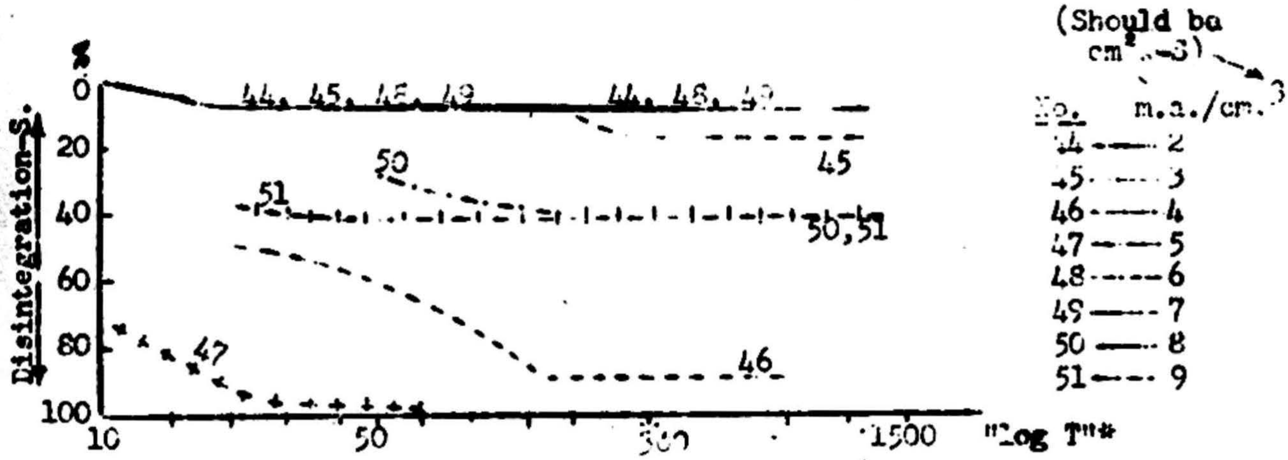


Fig. 6. DISINTEGRATION OF ANODE ZONE IN WATER AS INFLUENCED BY DENSITY OF CURRENT.

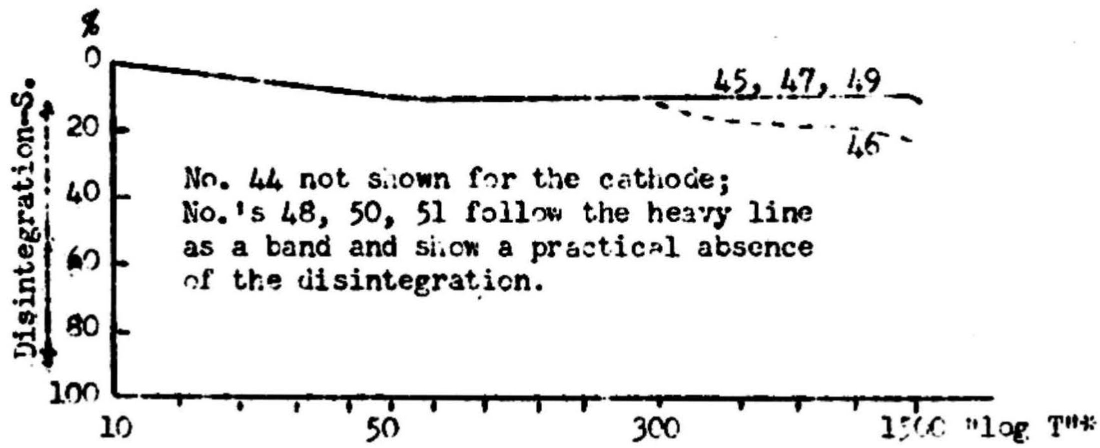


Fig. 7. DISINTEGRATION OF CATHODE IN WATER AS INFLUENCED BY DENSITY OF CURRENT.

*(A free-hand copy. The original is probably on log paper. Figures on the abscissa are the antilogarithms) S.

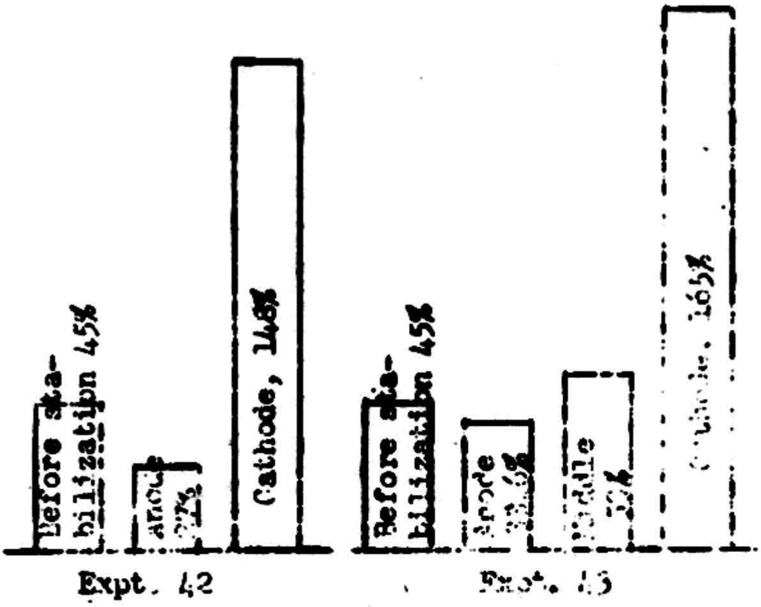


Fig. 8. SWELLING IN THE PRESENCE OF SODIUM SALTS

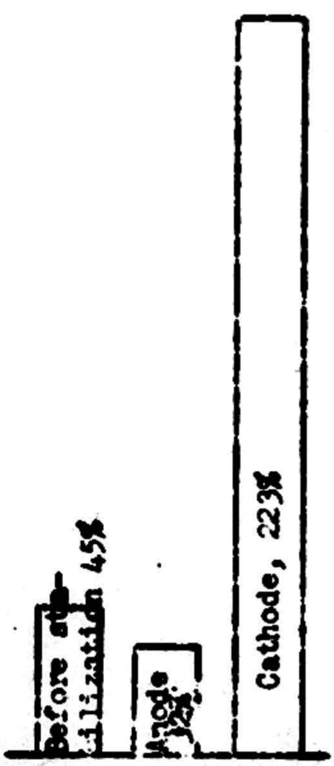


Fig. 9. SWELLING WITHOUT NaCl

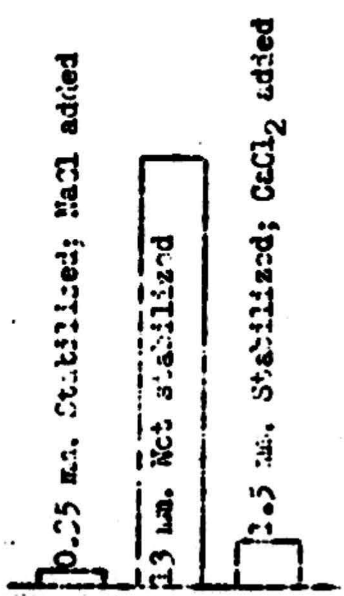


Fig. 10. HEAVING OF STABILIZED AND OF UNTREATED GROUND.

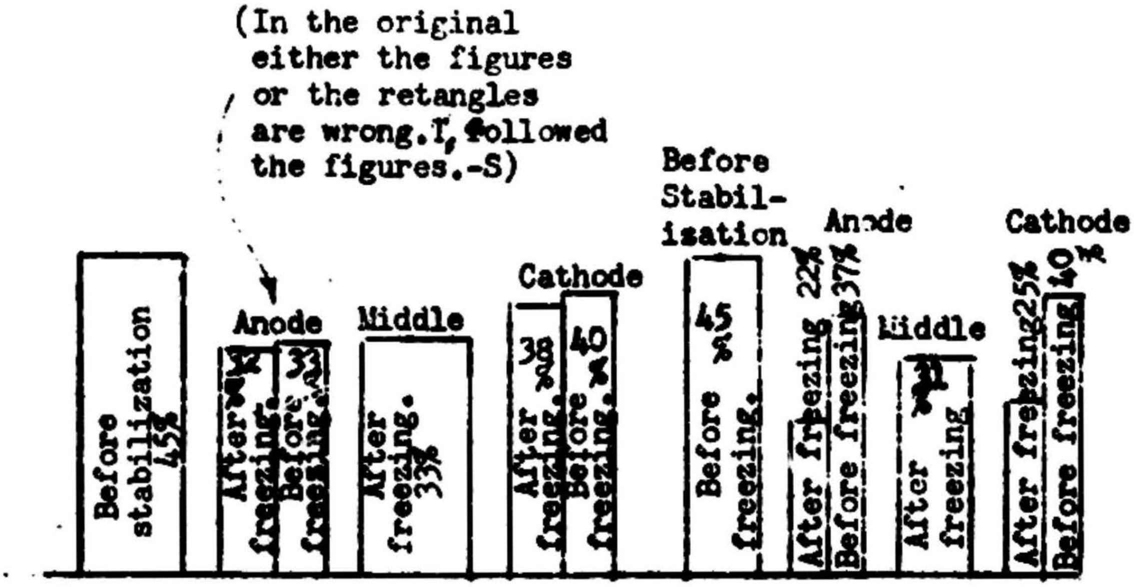


Fig. 11. SWELLING OF GROUND STABILIZED IN PRESENCE OF ADDED $CaCl_2$: BEFORE AND AFTER FREEZING.

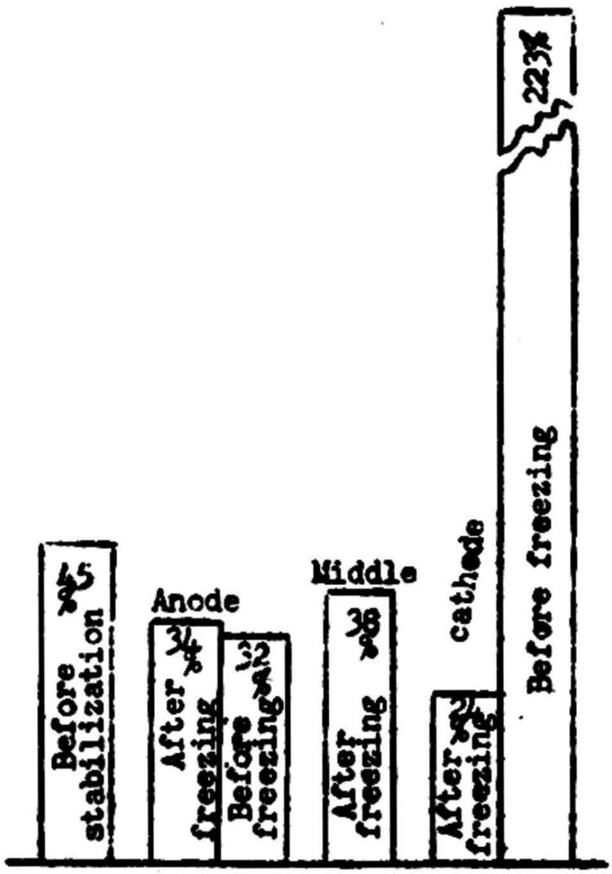


Fig. 12. SWELLING OF GROUND STABILIZED IN PRESENCE OF ADDED NaCl. BEFORE AND AFTER FREEZING

Fig. 13. IS A PHOTOGRAPH OF A DENSE SMOOTH CLOD INSIDE A WATER-FILLED UNCOVERED DESICCATOR. SOME MATERIAL, SLOUCHED-OFF, ON DESICCATOR BOTTOM

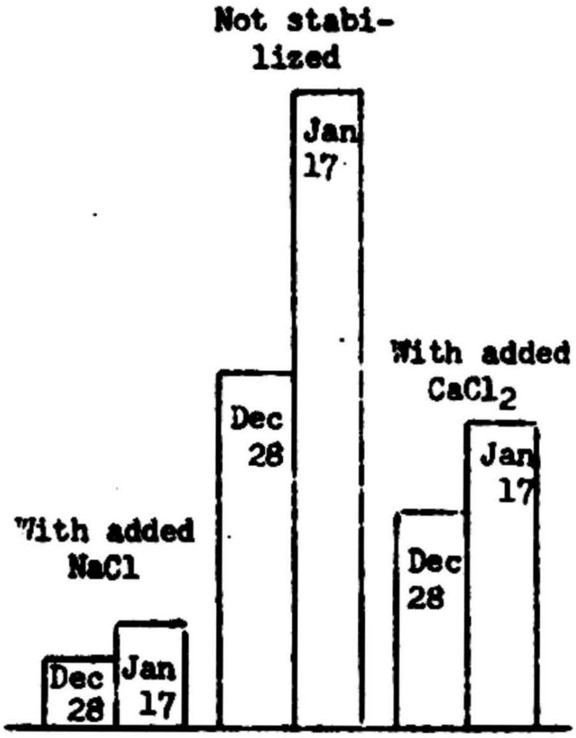


Fig. 14. FROST HEAVE OF STABILIZED AND OF UNTREATED GROUND