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Electro-Chemical Treatment of Clays

Traitement électro-chimique des argiles

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Summary

Typical soils of India were treated with electric currents and the changes in their engineering properties were studied. The result shows a decrease of plasticity and an increase of shear strength, permeability, compressibility, compaction density and structure, depending on the mineralogical composition. The treatment by carrying away exchangeable ions and replacing them by aluminium ions leads to a breakdown of the structure.

Introduction

Electro-chemical methods to improve the structural properties of clays have been tried out by a number of investigators. *L. Casagrande* (1939) for the first time studied them with a view to improving the bearing capacity and the drainage of fat clays. Later, *Endell and Hoffmann* (1936) reported that the shearing strength and bearing capacity of clays could be improved by passing an electric current through soil placed between aluminium and copper electrodes. *Winterkorn* (1948) also noticed significant changes in other engineering properties after such treatment. Continuing the previous investigations the influence of electric current on the common physical properties of the typical soils in this country were studied, and the chemical changes brought about in the clay were investigated. These investigations may be of help in problems connected with tubewells, and foundations on Mar and other plastic clays.

Experimental

Different samples of soil were first treated with 6% H_2O_2 to remove the organic matter, and then with HCl to remove calcium carbonate. These samples were later saturated with exchangeable calcium by leaching the acid-treated soils with $N-CaCl_2$ and finally by leaching with distilled water to free them from uncombined salt. This treatment brought the different soils to a similar condition by removing the varying amounts of humus, free salts and other exchangeable ions. The usual properties such as Atterberg's limits, permeability, shear

Sommaire

Des sols typiques des Indes ont été soumis à différents courants électriques et les modifications de leurs propriétés géotechniques ont été étudiées. Le résultat a montré une diminution de la plasticité et un accroissement de la résistance au cisaillement, de la perméabilité, de la compressibilité, de la densité de compactage et de la structure selon la composition minéralogique des sols. Le traitement mentionné provoque une rupture de la structure en éliminant les ions échangeables et en les remplaçant par des ions d'aluminium.

and consolidation characteristics of these soils in the untreated and treated conditions were then studied. Direct current was passed by means of a welder connected to 220 A.C. mains. The voltage available for the purpose was only 30 volts. The circular soil cake 10 cm in diameter and $2\frac{1}{2}$ cm thick was placed between an aluminium plate as anode and copper plate as cathode. The current was passed between the plates for 5 hours, keeping the soil between the plates saturated with water. After treatment the cake was dried, pulverised and stored in sealed bottles for other tests.

Atterberg-Limits

Liquid limits, plastic limits and plasticity indices of the soils in the untreated samples are given in Table 1, columns 3-5; columns 6, 7 and 8 give those for treated samples. It is clear that these constants for soils under investigation decrease after an electric current has been passed through them. It is worthwhile mentioning that with very plastic clays, namely 1 Po, and 1 MS, the liquid limit decreases by about 20% while soils with a comparatively compact structure, such as BB, P, 2K and 4B and 4MS, are subject to a decrease of only 10 to 12% on the average. Other soils 1K, 1B, 2MS show a decrease between these two extremes. From the structural point of view the clays with a liquid limit 53 and 58% can be improved to stabler clays with a liquid limit of about 35%. Examination of columns 4 and 7 shows that the plastic limit decreases slightly but not to

Table 1 Electro-Chemical Treatment of Clays with Effect on Engineering Properties

Sample Number	Description	Atterberg-Limits						Coefficient of Permeability ft./yr.		Shear Constants			
		Untreated			After Treatment with Electric Current			Un-treated	After Treatment with Electric Current	Untreated		After Treatment with Electric Current	
		LL %	PL %	PI	LL %	PL %	PI			ϕ	C Tons/sq.ft.	ϕ	C Tons/sq.ft.
1	2	3	4	5	6	7	8	9	10	11	12	13	14
4 K	Soils from Bundelkhand	53.7	18.4	35.3	35.2	17.8	17.4	.007	.05	26.7	0.68	33.5	0.55
1 K		45.2	21.2	24.1	30.7	14.2	16.5	.026	1.66	30.7	0.60	35.6	0.65
2 K		41.8	18.8	23.0	29.2	15.1	14.1	.025	1.85	35.2	0.32	38.8	0.35
BB	Clay from Res. Station Punjab	32.7	25.7	7.0	25.3	18.8	6.5	.067	11.25	37.8	0.32	38.0	0.35
P		35.8	24.0	11.8	23.8	14.3	9.5	.076	10.26	35.6	0.42	36.5	0.45
1 B	Soils from Bundelkhand	38.0	19.6	18.4	25.3	11.3	14.0	.009	.07	22.5	0.85	31.2	0.96
2 B		34.9	19.5	15.4	24.4	12.2	12.2	.016	.13	25.3	0.75	31.2	0.85
3 B		26.9	17.4	9.5	21.3	13.2	8.1	.026	1.65	33.8	0.62	35.7	0.65
4 B		33.4	18.2	15.2	25.8	17.2	8.6	1.253	13.25	38.2	0.45	38.9	0.50
1 Po.	Black Cotton fr. Poona	58.4	20.8	27.6	38.7	13.2	25.5	.003	.045	18.3	1.25	27.8	1.25
1 MS	Soils from Mysore Res. Station	57.3	23.9	33.4	37.2	13.0	24.2	.003	.044	20.8	1.05	28.7	1.15
2 MS		44.8	24.5	20.3	30.2	11.0	19.2	.005	.027	33.0	0.62	35.7	0.65
4 MS		38.2	30.8	9.4	30.1	20.9	9.2	.005	.028	20.3	1.15	30.7	1.17

a marked extent on treatment with electric current whereas the liquid limit does so markedly on treatment. In very plastic clays such as 4K, 1Po, and 1MS the plasticity index is reduced to a half in one case and to nearly 60% in the other case. With kaolinite soils such as BB, P, 4B and 4MS there is no marked decrease in the plastic limit. Other soils assume 40% of the original value.

Permeability

Columns 9 and 10 of Table 1 give the coefficients of permeability in untreated and treated soils. Evidently the permeability of soil increases with the passage of electric current through it. The most impermeable soils 4K, 1B, 1Po, 1MS and 4MS become 4-5 times more pervious and the rest of the soils which were comparatively pervious become 3 to 4 hundred times more pervious.

Shear Constants

Columns 11 and 12 of Table 1 give the angles of internal friction and cohesion for the soils in untreated conditions while columns 13 and 14 give those for the same after treatment. There is a marked increase in the angles of internal friction while cohesion remains practically the same, there being only a slight increase in some cases.

Consolidation Tests

Consolidation tests were carried out on these soils both in untreated and treated conditions. Fig. 1 gives the consolidation curves. The firm lines represent untreated soils and dash ones treated soils. A comparison of the two curves shows that there is a considerable increase in the rate of consolidation after passing an electric current. These tests were carried out on soils in remoulded conditions, thus the structure developed by the passage of the current was destroyed.

In order to study the effect of the current on soils in undisturbed condition tests were carried out in the ebonite consolidometer shown in Fig. 2. This was made in the laboratory. Soil

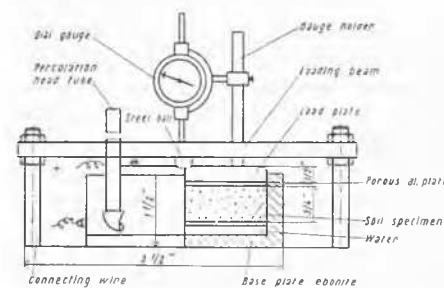


Fig. 2 Ebonite Consolidometer Consolidomètre d'ébonite

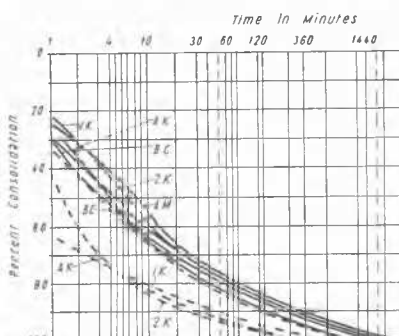


Fig. 1 Consolidation Curves Courbes de consolidation

at liquid limit was filled into the apparatus between perforated aluminium discs which were connected to a 12 volt battery. A fixed load was applied and the current was passed through for 2, 5, 10 and 15 minutes. Figs. 3 and 4 show the effect of the current on two soils examined in these conditions. The effect of load is to compress the soil and as soon as the current is applied with the load there is at once a break in the continuous time consolidation curve and the soil shows a significant compression. These figures also show the time consolidation relations for untreated soils. It is clear that the curves for treated soils are steeper, showing thereby that the rate of consolidation is increased by electrical treatment.

Mineral Composition

With a view to obtaining an idea of the nature of changes brought about by the current, mineralogical analysis of soils were carried out before and after treatment and the ratios $\text{SiO}_2/\text{R}_2\text{O}_3$ and $\text{SiO}_2/\text{Al}_2\text{O}_3$, and the basic exchange capacity

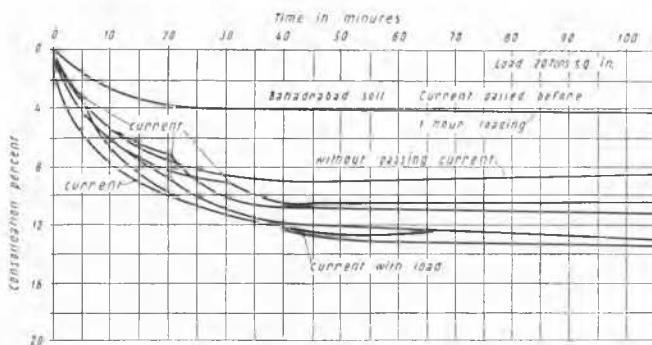


Fig. 3 Effect of Current on Bahadradab Soil
Effet du courant sur le sol de Bahadradab

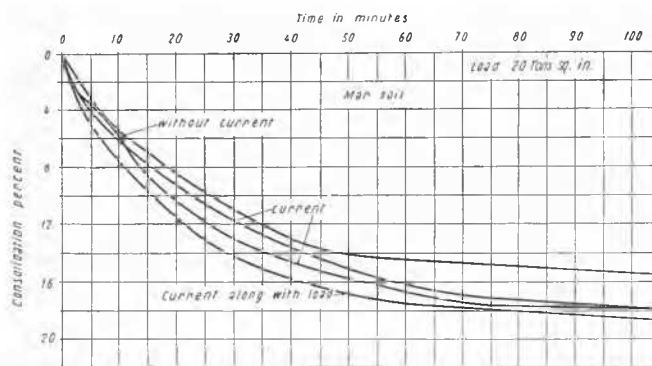


Fig. 4 Effect of Current on Mar Soil
Effet du courant sur le sol de Mar

determined. For this purpose portions of clay were separated from each of the soils by the usual methods and saturated with exchangeable calcium. These colloids were fused with sodium carbonate and total silica, sesquioxide and alumina estimated. Basic exchange capacity was determined by saturating with Ba which was replaced hydrogen from HCl. Table 2 columns 3, 4 and 5 give these results. Electric current was then passed through calcium saturated colloids and similar analysis was carried out. Columns 6, 7 and 8 of the Table 2 give the results for this part. A comparison of the two sets of results shows that both silica sesquioxide and silica alumina ratios decrease but that the basic exchange capacity increases, which contradicts the usual observation that basic exchange capacity varies in direct ratio with the silica alumina ratio.

In order to find out whether the aluminium had entered exchange complex and had deposited as free aluminium oxide or hydroxide, the electrified soils were first leached with N-BaCl₂ and displaced aluminium determined in the leachate. The same soil was then leached with N/20 HCl and the Al collected in the leachate was estimated. Columns 9 and 10 of the Table 2 give the figures for exchangeable Al and free Al for each soil. These figures indicate that with the passage of electric current through the soil some exchangeable Al enters the exchange complex replacing other bases, and a certain amount of aluminium hydroxide is formed which forms a deposit and is a binder of clay very much like calcium carbonate. This salt must encourage crumb structure and granulation responsible for the increased shearing strength and bearing capacity. Further the exchangeable Al which has entered the exchange complex also contributes towards porosity and granulation. The figures in the column 9 of Table 2 show that of the total basic absorption capacity only a portion of exchangeable Al is absorbed. This is significant. The low voltage applied, the short duration of treatment and the relatively low moisture content go a long way to explaining why the reaction is incomplete. Under suitable conditions of voltage and duration of current all basic centres are replaced by aluminium.

Table 2 Electro-Chemical Treatment of Clays with Effect on Mineral Composition

Sample Number	Description	Mineral Composition						Exchangeable Al and free Al after Treatment		Mineralogical Analysis of Treated Soil and Removing Free and Exchangeable Al		Base Exchange Capacity m.e.
		Untreated			After Treatment with Electric Current			Exchangeable Al m.e.	Free Al m.e.	$\frac{\text{SiO}_2}{\text{R}_2\text{O}_3}$	$\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3}$	
		$\frac{\text{SiO}_2}{\text{R}_2\text{O}_3}$	$\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3}$	Base Exchange Capacity m.e.	$\frac{\text{SiO}_2}{\text{R}_2\text{O}_3}$	$\frac{\text{SiO}_2}{\text{Al}_2\text{O}_3}$	Base Exchange Capacity m.e.					
1	2	3	4	5	6	7	8	9	10	11	12	13
4 K	Soils from Bundelkhand	1.93	3.40	58.50	1.76	2.88	61.25	2.670	36.20	1.85	3.25	52.25
1 K		1.75	2.15	43.40	1.62	1.95	45.53	1.796	25.32	1.25	1.59	40.15
2 K		1.33	2.04	36.53	1.05	1.85	40.15	1.670	32.00	1.29	1.85	30.17
BB	Clay from Res. Station, Bahadradab	1.14	1.53	24.88	1.05	1.45	30.25	2.300	33.80	1.05	1.25	21.30
P	Clay from Punjab	1.19	1.63	34.28	0.95	1.25	36.15	2.140	29.50	1.05	1.41	29.30
1 B	Soils from Bundelkhand	2.08	3.83	63.25	1.52	2.95	65.15	2.532	41.03	1.93	2.95	61.05
2 B		1.42	2.33	45.39	1.15	1.95	47.42	1.703	41.25	1.31	2.12	40.15
3 B		1.26	1.98	33.63	1.05	1.45	35.75	1.256	36.23	1.12	1.73	28.15
4 B		1.08	1.36	20.59	0.85	1.05	25.25	0.230	33.15	0.95	1.25	18.35
1 Po.	Black Cotton from Poona	2.53	4.10	83.43	1.45	3.25	91.35	0.356	16.18	2.15	3.95	78.15
1 MS	Clay from Res. Station, Mysore	1.98	3.52	63.42	1.75	2.85	64.53	0.565	17.12	1.93	3.45	58.35
2 MS		1.20	1.56	32.10	1.05	1.20	35.25	3.532	29.32	1.05	1.23	28.78
3 MS		2.14	3.56	65.25	1.85	2.85	70.35	4.189	30.251	2.05	3.12	60.17

A mineralogical analysis carried out after exchangeable and free Al had been determined is given in the last three columns of Table 2. The silica sesquioxide and silica alumina ratios decrease compared with those of untreated soils columns 6 and 7. This is because the free Al present in the soil after being removed reduces the alumina content. The last column of Table 2 shows that the basic exchange capacity ultimately decreases in comparison with the figures of column 5. The higher figures shown in column 8 may be due to the fact that aluminium oxide or aluminium hydroxide may be acting as an activated precipitate, absorbing some of the ions together with the rest of the clay surface.

After this precipitate had been leached out by HCl, the resulting colloidal clay had a basic exchange capacity much lower than that of the original untreated soil. This is what was expected, namely that, with the decrease of $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratio, the basic exchange capacity would also decrease.

Thus the passage of electric current through a soil between Al and Cu results in partial or total replacement of exchangeable bases by Al as shown in column 9 of Table 2. The small voltage and short duration of its application introduces only 1 or 2% of the exchangeable aluminium. This happens in two stages. As soon as a voltage is applied the exchangeable ions migrate to the cathode, leaving hydrogen ion on the surface. The resulting hydrogen soil has a changed structure in which some of Al form crystal lattice which is set free and is absorbed by the clay particles. The fact is verified by the experiment described.

Colloidal portions from a Mar clay were leached firstly by N/20 HCl so as to replace other exchangeable ions by hydrogen. It was then leached with N-BaCl₂ so as to saturate the exchange complex with Ba. The cycle was repeated every time to determine the total Ba absorbed and exchangeable Al replaced by Ba. The former gave the basic exchange capacity of hydrogen soil formed by leaching with HCl. Table 3 gives the results.

It is thus clear that exchangeable hydrogen renders mobile some Al from Si-O-Al framework resulting in the change of structure and absorption of Al on the surface. The change in

Table 3

	<i>Base Exchange Capacity Mill. equ.</i>	<i>Exchangeable Al and Fe %</i>
1st Treatment	44.58	0.3525
2nd Treatment	39.26	0.3256
3rd Treatment	36.03	0.3010
4th Treatment	32.42	0.2842

structure is affected by a loss of base absorption capacity in every cycle.

A precisely analogous set of changes takes place as a result of the passage of electric current. The mineral ratios as well as basic exchange capacity decrease so that an expanding Beidellite structure tends to become more compact.

Besides appearance of exchangeable Al and disturbance in the crystal structure, there is deposition of Al as oxide or hydroxide in the soil which serves as a binder of the clay particles in much the same ways as CaCO₃ does. The soil becomes more granular and forms stabler aggregates. Column 11 of Table 2 gives the figures for free aluminium formed. It comes from Al anode and is also freed from clay nucleus.

These chemical changes explain the change in the physical properties shown in Table 1 and the consolidation tests described earlier. Plasticity decreases, permeability and shear strength increase because of exchangeable Al, which encourage more compact crystal structure, loss of reactivity and the granulation of the soil mass.

Further work with various electrical and chemical conditions is in progress.

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