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STRATEGIC USE OF SOIL IN WAR OPERATIONS

The role of Dispersion, Flocculation, Thixotrophy and Plasticity of clay.

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Introduction.

For preventing the movement of enemy troops over land in war operations, various strategic methods have been developed. One interesting method would be to convert a long belt of land across the enemy track into a swampy and marshy one. If the swampy belt is sufficiently deep and wide, the enemy movement would be practically inhibited.

Conversion of a dry land into a swampy one and its maintenance with the minimum of water supply involves a study of the various problems in soil science. An effort has been made in this paper to present some of the important properties of soils and to briefly refer in the light of these properties to the production maintenance and the strategic use of swampy soils in war operations.

The Soil.

Soil is a disperse system consisting of various complex substances in different states of subdivision—molecular, colloidal, and coarse. The colloidal matter has an important role in the soil. Most of the properties of the soil can be ultimately traced to the colloidal properties of the clay fraction of the soil.

The colloidal clay particles of soil may be found in a state of almost complete dispersion or in a condition of nearly perfect aggregation. In most soils, however, the aggregation is partial.

Mechanical analysis of soil.

The Atterberg scale of the limits of particle sizes has been adopted by the International Society of Soil Science. The following are the mechanical fractions of soil.

Soil Fraction.	Limits of particle size.
Stones and Gravel.	20 mm — 2 mm
Coarse sand.	2 mm — 0.2 mm
Fine sand.	0.2 mm — 0.02 mm
Silt.	0.02 mm — 0.002 mm
Clay.	less than 0,002

The colloidal clay is a fraction of clay and its effective particle diameter is less than 100 mu (0.0001 mm). The soil passing through a 2 mm sieve is called fine earth.

Separation of the soil fractions.

For dispersion of the soil, the International method A is commonly adopted (14). According to this method the soil is treated with hydrogen peroxide to remove the organic matter. It is next treated with hydrochloric acid to decompose the carbonates. The filtered and washed soil is passed through a 0.2 mm. sieve to separate coarse sand. The material passing through the sieve is treated with ammonia, shaken and allowed to stand. After 4 minutes and 48 seconds, a sample is taken out at a depth of 10 cm. and estimated for clay and silt. Next, the suspension is shaken and a sample taken after 8 hours at a depth of 10 cms. and estimated for clay. Silt is obtained by difference. For the estimation of fine sand, the bulk of the supernatant liquid is poured away and water added to the sediment to a height of 10 cms. After 4 minutes and 48 seconds, the turbid liquid is poured and water again added to the same height. The process repeated until the supernatant liquid is no longer turbid. The residue is fine sand. The above procedure adopted for the separation of the soil fraction is based upon the application of Stokes' law for sedimentation velocity of suspended particles.

$$v = \frac{2\,(D-d)\;gr^2}{9\,\eta}$$

where v = Velocity of a spherical suspended particle.
r = radius of particle.
D = Density of particle.
d = Density of liquid.
η = Viscosity.
g = acceleration due to gravity.

Clay and the Colloidal content of soil.

The percentage soil fractions vary considerably with different soils. For instance, the percentage of coarse sand, fine sand, silt, clay and organic matter of red laterite soil are 40.6, 22.6, 2.9, 30.7 and 0.25 whereas those of black cotton soil are 5.2, 45.5, 15.5, 33.9 and 0.63 respectively (11).

The colloidal content of soil is estimated by studying the absorption of ammonia and water. According to Joseph (14), the whole of the clay fraction in soil can be obtained in the colloidal condition and therefore the clay content can be taken as a measure of the colloidal content. This method is generally accepted now. Direct estimation of the colloidal content is also possible by extraction by employing a continuous flow-centrifuge.

Constitution of clay.

Naturally occurring clay is rather a complicated mixture of hydrated silicates of the alkalies, alkaline earths, iron and aluminium generally with some sand and organic matter. Colloidal silica, silicates and metallic hydroxides with colloidal organic matter usually form a sheath round the particles and account for many of the properties of clay.

Colloidal clay consists of new secondary minerals (silicates) associated with small amounts of oxides. The bulk of the soil colloid is crystalline as revealed by X-ray analysis. The primary soil minerals such as quartz, micas and feldspars are present in small amounts. The soil colloids do not result from a mere reduction in size of the original mineral with alteration caused by surface withering but are formed by secondary synthesis of the degradation products of the primary minerals.

Clay as acid.

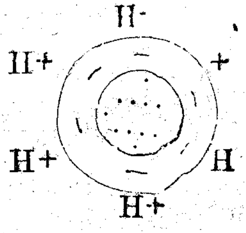
Electrodialysis of clay removes 20-25 per cent of the total bases. Calcium and sodium are removed almost completely whereas potassium and magnesium are more firmly held. If a clay from which no more base can be removed by electrodialysis is suspended in water, the suspension will be neutral whereas the clay paste itself will have a pH of 2.0-3.5. Such a hydrogen saturated clay is known as clay acid. Basic clays are prepared from clay acid by adding the proper amount of the hydroxides of sodium, potassium and ammonium etc.

Clay acid is a complex colloidal weak acid with a dissociation constant of approximately 10^{-8}. The clay acid behaves like a tri-basic acid, the three acidic hydrogen atoms being replaceable by metals. The salts derived are known as clayates. Clay acid is as strong as carbonic acid and is much stronger than silicic acid.

Clay in general is flocculated by acids and salts. Small amounts of alkalies and alkaline salts deflocculate.

Structure of colloidal clay particle.

Clay is an irreversible or slowly reversible colloid. It is hydrophobic or slightly hydrophilic. It is negatively charged, sensitive to electrolytes and is easily coagulated by cations. The structure of the charged colloidal clay particle is shown in figure 1 below.



G. 1.

In water the particle is negatively charged owing to the preferential adsorption of OH ions. The stability of colloid depends upon the ability to form a diffuse electrical double layer.

Many important properties of soils such as permeability, capillarity, adsorption, moisture content etc. are dependent upon the colloidal content of soil. Over about 18 per cent, clay gives a heavy soil while under about 4 per cent a sandy soil of low water retaining capacity. Effect of lime on a clay soil is marked. Dressing with calcium carbonate makes an 18 per cent clay soil act like a 12-14 per cent clay soil.

Bentonites.

Bentonites are fine clays resulting from the dust deposited by ancient volcanoes. These are highly colloidal and swell in water like gelatin or glue.

Humus the organic colloid.

Constitution of humus.

In addition to the inorganic colloids, soils also contain organic colloids, the most important of which is humus or humic acid. Humus is the ultimate nondecomposable product of the decay of plant and animal remains and debris. Humus is acidic and of complex chemical nature.

Protective action of humus.

Humus is a reversible Hydrophilic colloid, less sensitive to electrolytes and has protective action on the inorganic colloid. The stability of colloidal humus is due to layers of water of hydration. Colloidal humus is negatively charged. Its structure is shown in figure **2 below.**

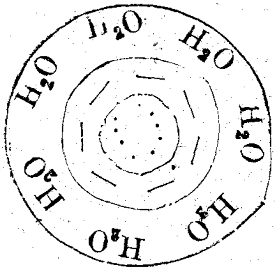


FIG. 2.

Protective action of humus.

Humus acts as a protective colloid and makes the soil less sensitive to the ruinous coagulating effects of an excess salt. Thus 15-20 per cent humus will almost obliterate the difference between a clay soil and a sandy soil.

Humus is a good culture substance for bacteria and micro organisms beneficial to the soil. Humus adsorbs moisture and plant foods such as nitrates and phosphates. The adsorption of moisture is an important property, because the amount of moisture retained by the soil in dry weather is proportional to the colloidal content.

Water holding capacity of the soil.

Water holding capacity of the soil is a property which is of great importance in agriculture. A portion of water held by the soil is either adsorbed water or water of crystallisation. The remaining water is held in the capillaries of soil. The total water holding capacity of the soil is influenced by the height of the soil column and mode of packing. But the colloidal content is the most important factor in determining moisture holding capacity. Some ordinary clays hold as much as 75 per cent of water whereas coarse sand retains only 20 per cent.

The composition of the surface of clay particles consists of Si-O-Si planes and possibly OH planes on which the water is adsorbed. As in hydrous gels, a part of adsorbed water is nonfreezable until the temperature is reduced far below zero. This doubtless is of importance in preventing complete desiccation of the soil by freezing.

The relation between vapour pressure and moisture content of soil was first studied by Thomas (12) and later by Puri, Crowther and Keen (9). A soil retains more of water during dehydration than during hydration. This phenomenon of hysteresis has been studied in sufficient detail by Sarada Gulvady, Rao K. S., and Rao B. S. (11) with different soils and soil fractions. The significance and importance in nature of this hysteresis effect exhibited by soils have been discussed.

Dispersion of clay.

Colloidal clay is dispersed or peptised on shaking with water but the process is greatly increased by electrolytes containing strongly adsorbed anions such as alkali hydroxides, carbonates, silicates and is retarded or prevented by electrolytes with strongly adsorbed cations. Substances which favour dispersion or peptisation are known as dispersing or peptising agents. Ammonium hydroxide, sodium carbonate and sodium hydroxide are good dispersing agents. If clay is shaken with ammonium hydroxide, sodium carbonate or sodium hydroxide, a stable colloidal suspension of clay is obtained. Sodium silicate, phosphate, tannate are also effective as dispersing agents due to alkalinity, to adsorption of anions and in some cases to removal of polyvalent cations.

In brief the stability of colloidal clay is due to the electric charge (the electrokinetic potential, i.e.,ζpotential) on the colloidal particle and also due to the organic colloid (humus) which has protective action. Therefore, any agent or process by which these two factors are favoured will enhance stability and thus a stable dispersion can be obtained.

Clays containing appreciable amounts of sulphates of calcium and magnesium are difficult to disperse because of the precipitating action of calcium ions. On the other hand, clays containing protective colloids such as humus are easily dispersed. In technical practice tannin is sometimes added to facilitate the dispersing action of the electrolytes and to increase the stability of the suspension.

The moisture content of the soil also affects the degree of dispersion of the soil(10). The greater the water content of the soil greater is the degree of dispersion.

Flocculation of clay.

The colloidal clay particles which are negatively charged repel each other and are thus prevented from sticking to one another. The stability of a colloid is consequently due to the charge present on it. The particles can come in contact only if forces due to Brownian movement overcome the repelling forces due to electric charge. If these forces are equal or the repelling force is smaller, slow coagulation occurs. If a colloid loses its electric charge entirely, rapid coagulation will ensue. The coagulating ability can be traced back to the compensation of the electric charge of the particle which stick the particles in the absence of the repelling forces. The negatively charged clay is flocculated by positively charged cations. Flocculation is due to the removal of charge owing to the preferential adsorption of ions of opposite charge. The different cations have different coagulating powers and can be arranged as follows :—$H. > Fe > Al > Ca > Mg > K > NH$ $Na > Li$. This series, with the exception of hydrogen, is in accordance with the Schulze—Hardy valance rule which states that the coagulating power of an ion increases with its valance.

The anions have stabilising influence on clay. The stabilising powers of anions are as follow :—$OH > SO_4 > NO_3 > Cl$.

The ζ potential has influence on the flocculation value. It takes more of electrolyte to coagulate a clay with high potential than one with a low potential. There is a critical potential below which or at which the flocculation value is zero i.e., the colloid at the critical potential is unstable and tends to coagulate. The critical potential for clay is 42 milli-volts.

Thixotropy of Clay.

If hydrochloric acid is added to sodium silicate, a gelatinous precipitate of hydrated silica is ordinarily obtained. But if the concentrations of the two solutions are suitably fixed, a clear solution is obtained on mixing. The mixture on standing exhibits increasing rigidity and opacity with time and finally sets to a hard translucent or opaque jelly. This interesting phenomenon of the transformation of a liquid sol into a solid jelly is known as gelation. Gelation is irreversible in the case of silica.

If a suitable amount of an electrolyte is added to a fairly strong sol of ferric oxide or alumina and the mixture allowed to stand, it will set to a jelly. If the jelly is shaken, the sol is reformed which will set again on standing. The process may be repeated any number of times. This isothermal reversible sol-gel transformation has been termed thixotropy. The phenomenon is observed only in fairly strong hydrous oxide sols. But bentonite sols containing less than 1 per cent are thixotropic. For thixotropic behaviour, the potential on the colloidal particles must be reduced to the point at which the particles stick together to form a loose network structure when the sol is allowed to stand. If reduced too far, gelatinous precipitate is produced. Small particle size, plate or rod shaped structure favour thixotropic behaviour.

Clays containing exchangeable sodium and potassium ions flocculated by the corresponding chlorides or clays suspended in chloride solutions of above normal concentration give thixotropic gels.

Dialysed bentonite does not exhibit thixotropy but does so after the addition of alkali hydroxides.

Thixotropy is more pronounced, the smaller the particle size. With particle diameter of 150 Å, a 0.05 per cent bentonite gives a thixotropic gel. Bentonite shows also the phenomenon of Rheopexy. The Rheopetic setting time is about 1/100 of the normal setting time when undisturbed.

Plasticity of clay.

The working property of clays depends largely upon the size and the degree of dispersion and hydration of their constituent particles. These factors are in turn influenced by the presence of protective colloid (Humus), salts and pH. Thus the clay of Mesopotamia is baked into bricks by mere exposure to the sun whereas other varieties of clay require firing.

Clay is flocculated by acids and acid salts and deflocculated by alkalies and alkaline salts. Clay slip prepared with a little sodium hydroxide or sodium carbonate can be readily poured or cast even though it contains less water than a stiff mass of clay and water without alkali. On adding a little acid to such a fluidified clay slip, the mass immediately becomes so stiff that it will not fall from the inverted vessel.

Plasticity is defined as the property of a material which enables it to change its shape without cracking when subjected to pressure, the new shape being retained when the deforming stress is removed.

Plastic clay consists of minute, non-plastic grains surrounded by films of a gelatinous material saturated with water when maximum plasticity is developed. With excess water, clay becomes sticky, with still larger excess, a non-plastic sol or clay slip is formed. If clay is dried the gelatinous matter shrinks, becomes hard and horny and plasticity disappears only to reappear when the clay is moistened again.

Gelatinous binding material in the colloidal fraction of soil is chiefly hydrous aluminosilicates with hydrous oxides of aluminium, silicon and iron. On drying it loses the power of taking water and reforming a gel. According to Bancroft and Jenks, the presence of at least one salt which peptises clay and one which tends to coagulate it is necessary. On this hypothesis, a non-plastic clay is one which contains little salts.

Hydrous oxides or hydrous aluminosilicates impart plasticity even after drying provided that primary particles are prevented from coalescing or agglomerating. Coalescence is inhibited by peptising agents. Humus possesses the properties of both a peptising agent and a protective colloid. It plays an important role in the development and maintenance of plasticity in many clays.

Clay suspensions do not obey Poiseuille's law except at great dilutions. Typical flow patterns at high pressures are expressed by two constants, one measured by the interscept on the stress axis (the yield value or shearing strength), the other analogous to viscosity which can be calculated from the slope (stiffness or pseudo viscosity). When clay is in the flocculated state, both shearing strength and pseudo viscosity are higher.

Plastic properties depend upon colloidal stability. This in turn depends upon the electrical double layer the magnitude of which is determined by the structure and composition of the clay as well as the nature and concentration of added salts.

Ceramists attribute plasticity of clay to the chemical characteristics of molecules or the plate-like structure of the colloidal particles. Bradfield compares the difficulty of separating two glass plates with a film of water with two spheres in contact at a single point having an annular ring of water. The plate-like structure would certainly influence the plasticity of clay but it is still an open question whether shape of hydrous particles alone is sufficient to produce the phenomenon.

Ordinarily the amount of inorganic colloidal matter in clay rarely exceeds 1.5 per cent. If the content is low, the clay is sandy, has a low plasticity and is said to be weak or lean, if high the clay will be sticky rather than plastic and is said to be fat.

Electron microscopic examination of clay.

During recent years, electron microscope is being used by various investigators in soil research. With the aid of this instrument, the processes of dispersion, flocculation, orientation, grinding, cleavage of mineral particles and the alteration of the mineral particles through withering have been studied by Jackson (6). Electron microscopic examination has been helpful in exploring new aspects of colloid phenomena which were not accessible to any other technique known so far.

Technology of clay.

The study of the colloidal properties of clay has been found very fruitful in relation to soil science, agriculture, civil engineering, construction of roads, reservoirs and canals.

Seepage of water from lakes has been overcome by changing the pervious natural soil into an impervious sodium soil by flooding with sea water.

In constructing canals, a layer of bentonite is sometimes added to the sides and the bottom. This swells in contact with water and reduces loss by seepage.

Clays upon which certain surface active materials such as soaps have been precipitated are owing to their diminished hydrophilic nature less affected by water, a fact which is used in road engineering for soil stabilisation.

In the drilling of oil wells, a drilling mud, usually bentonite, is used in the drilling fluid. The object of the mud is to keep the rock fragments produced in suspension when the drill is at rest so that sedimentation and caking are avoided. The thixotropic nature of bentonite suspension makes it very suitable for this purpose and its low viscosity when sheared enables the liquid containing the rock fragments to be pumped readily out of the bore hole.

An interesting recent development in clay technology has been the production of flexible films of clay, by careful spreading and drying of thixotropic gels of montmorillonite preferably those of high ion exchange capacity. The clay particles align themselves during evaporation and form interweaving thread-like aggregates giving rise to a microfabric structure. By binding the particles with suitable ions introduced by a process of ion exchange, the films have been made resistant to moisture as well as to organic solvents. The structure is now comparable to that of muscovite and might therefore be termed synthetic mica.

Thixotropic bentonite finds application in the fluid of adhesives.

Electroosmotic studies and technology of clay.

Soils can be stabilised (3) by the drying resulting from the heat generated by the passage of electric current through the soil. By electroosmosis, water can be removed at the cathode and the soil consolidated. This method has been used to promote drainage in water logged soils, to increase the bond between piles and soils and to introduce chemicals such as calcium chloride.

The investigations of Maclean and Rolfe (7) on electroosmosis in soils are interesting. Electroosmosis experiments on a cylindrical specimen of wet soils are described. For a given solution the amount of water expelled at the cathode is proportional to the quantity of electricity passed through the specimen up to the point, when the soil at the anode became too dry to act as a conductor. On passing the current through the wet soil, the soil dried out at the anode and water was expelled from the soil at the cathode. Large currents cause considerable heating at the anode. This enhances the water movement caused by electroosmosis alone. When the soil dries out at the anode, the rate of expulsion of water decreases to zero. The weight of water expelled by a given quantity of electricity is the highest for sandy soils and lowest for heavy clay soils.

Electroosmosis is applied to the removal of water from peat, in dewatering moist clay and in drying dye pastes. A novel application is in cutting clay into bricks by means of wires. Ordinary lubricant must be used on the cutting wires to prevent the clay from adhering to them. If the wires are made cathode and the anode inserted in clay block, the clay no longer sticks to the wire and power consumption is reduced to 20-30 per cent. The effect is due to the formation by electroosmosis of a lubricating film of water on the cutting wires. Similarly, by lubricating the ploughshare with a film of water, the energy required to plough the clay is reduced by the process of electroosmosis but unfortunately the saving in mechanical energy is not great enough to compensate for the electrical energy required.

Soil hardening process.

Clayey, water logged and sandy soils as well as artificial deposits such as coal ash dumps, cinders, and slag may be hardened by spraying with a strong solution of calcium chloride or magnesium chloride. A second spray of a strong solution of sodium hydroxide or potassium hydroxide precipitates the hydroxides of calcium and magnesium which harden the soil after sodium silicate is poured on to the soil.

In the construction of aircraft runways, roads, floors and other surfaces, surface hardening is brought about by applying to the earths surface an aqueous solution of sodium oleate or rosinate and aluminium sulphate so as to form a water repellant and water insoluble salt.

Research to develop methods for transforming soft soils into stable surface that will support heavy motor vehicles and airplanes is being conducted in the United States of America. Researches from the Massachusetts Institute of Technology, indicate that mud can be changed into a tough rubbery substance in less than 5 hours by a chemical process. In this process, calcium acrylate is mixed with the soil containing about 40 per cent of water according to the "Wall Street Journal". Sodium thiosulphate and ammonium persulphate are added as catalysts. The latter do not enter chemically into the compound, but generate heat and cause the calcium acrylate molecules to lock together. 5 hours after the treatment, soil becomes an elastic mass with a tensile strength of five to ten pounds per square inch. If the stabilised soil is allowed to dry over a week, it develops a tensile strength of 500 pounds per square inch, equal to the strength of concrete.

Soil drainage as influenced by dispersion.

By a study of certain soils which showed marked obstruction to drainage, Gallagher and Walsh (5) arrived at the following conclusions :— (1) The obstruction to drainage is much more significantly related to the states of flocculation of the soils than to the mechanical composition. (2) The state of flocculation of many soils is markedly influenced by carbondioxide. The flocculating influence of lime on clay appears to be dependent upon the presence of this gas. (2) The addition of small quantities of colloidal soils has a marked effect. Silica and others promote dispersion while proteins and sesquioxides promote flocculation. The dispersing colloids show a protective influence against the flocculating effect of carbondioxide.

Patter (8) reports that the drainability of soils can be accurately and quickly determined by making a mechanical analysis of the soil. If the soil is high in clay colloids, it will drain poorly and if low it will drain well. If the percentage of sand is high, the soil will drain well. If low, the higher the silt content as compared to clay the better the soil will drain.

Application of the properties of clay to the strategic use of soils in war operations.

Conversion of dry soil into swampy soil.

Some of the important properties of clay such as dispersion flocculation, plasticity and thixotropy have been discussed. Application of these prperties to strategic use of soils in war operations may now be considered. The main object is to convert the dry soil into a swampy one over a sufficiently large area and depth such that the movement of the enemy across the belt of swampy land is hindered.

Different types of soils, differing markedly in their properties have been recognised. The following are the three distinct types The acidic soil of humid temperate regions, the alkaline soil of the arid zones and the neutral soil of the tropics—an intermediate between the two extreme types—rich in calcium and containing a reserve of calcium carbonate. The acidic soil is produced by the gradual displacement of calcium by hydrogen and the alkaline soil by sodium.

The humid temperate soil is rich in humus and silicic acid, has low permeability to water, is highly plastic and cannot be ploughed without puddling for several days after a heavy rain. Whereas the red soil of tropics with similar colloidal clay content has high permeability to water, is nonplastic, drains quickly and can be plughed within a few hours after tropical rainstorm. The tropical soil consists largely of the hydrous sesquioxides of iron and aluminium and because of their red colour it has been called laterite soil.

Soils saturated with bivalent cations have crumbling structure and those with univalent cations hydrolyse greatly and are highly dispersed. Hydrogen and tervalent cations are held more strongly than bi or univalent cations.

The dispersion coefficients for clay acid and a number of clayates are determined. Lithium and sodium salts give high dispersion coefficients and low rates of percolation to water, whilst treatment with gypsum increases the permeability and lowers the dispersion coefficients. Highly acidic soils gave a low dispersion coefficient and high rate of percolation. Irrigated soils gave a comparatively higher dispersion coefficient than unirrigated soils.

Indeed the slow rehydration of clay is familiar to all who have struggled with a garden, after a prolonged period of draught. The soil does not become sticky even after heavy rain but during a spell of wet weather the soil becomes so sticky as to be almost unworkable.

From the point of view of strategy, the soil should be highly dispersed and should have low rate of percolation or poor permeability to water. This condition is naturally met with in alkaline soils. In such soils all that is necessary is to irrigate the soil with water. With other soils however, peptising agents like sodium silicate, sodium carbonate, ammonium hydroxide or sodium hydroxide should be added. The amount to be added can be fixed by determining the dispersion coefficient of the soil.

Humus, the organic colloid, has been established to be a good protective agent. If the soil is poor in humus, addition of certain protective colloids like gum arabic, tannin facilities dispersion of the soil. With arid soils in which rehydration is slow, repeated irrigation with water is necessary, after the addition of the deflocculating and protective agents.

Plasticity of soil is another factor of strategic importance. The soil may be highly dispersed and stabilised but if it is too stiff and rigid the strategic value is lost. Therefore, it is necessary to maintain the soil in highly plastic condition. The property of plasticity is determined by the degree of dispersion, stability of colloid and water content of the clay. Therefore, in addition to the first two factors, maintenance of optimum water content in the soil is necessary.

From a discussion of the thixotropic property of the clay already presented, it seems to be necessary to introduce into swampy soil the thixotropic behaviour. Clay containing certain amounts of sodium and potassium salts is known to behave thixotropically. Thixotropic property can be introduced into the swampy soil by adjusting the concentration of sodium and potassium salts. If for instance this is not practicable, small amounts of bentonite, which is known to be highly thixotropic, may be added.

Introduction to soil of the thixotropic property is important in view of the fact that it acts as a buffer for the effect of the possible variations in water content of the soil. With loss in water, plasticity changes over to rigidity. This change is counteracted to certain extent by the thixotropic property.

Thus from the foregoing considerations, dry arid granular earths can be converted into swampy ones having a high degree of dispersion, plasticity and thixotropy.

Reclamation of the swampy soil.

After the strategic use, the swampy sticky soil can be reclaimed for normal use of heavy traffic by the various processes such as flocculation, drying and surface hardening.

Hardening can be effected by the flocculation of the highly dispersed soil brought about by the introduction of flocculating agents like calcium salts. Calcium can be added directly and the process can be hastened by electroosmosis. On flocculation the plastic soil sets to a hard jelly and thus the rigidity is restored.

Swampy soil can be hardened by drying brought about by the removal of water. The removal of water is quickened by electroosmosis. Drying is brought about partly by heating caused by the passage of electricity.

Chemical methods for surface hardening can also be adopted. Surface hardening by the use of sodium acrylate and other chemicals has been described. Chemical methods of surface hardening have already yielded results of far reaching importance and are still capable of further development.

References.

1. Alexander J.—Colloid chemistry. Theoretical and applied. Vol. III. Chemical Catalogue Company, Inc. New York, 1931.
2. Alexander J.—Colloid chemistry Principles and application. Chapman and Hall Ltd., London, 1937.
3. Baber E. S.—Roads and Streets 9, No. 6, 64-5, 1948.
4. Baver L. D.—Soil physics. John Wiley & Sons, Inc. New York, 1948.
5. Gallagher and Walsh.—Proc. Royal Irish. Acad. 49B. 61, 1943. Roads Abstracts 11, 93, 1944.
6. Jackson.—Soil science, Soc. American Proc. 11, 56-63, 1946.
7. Maclean D. J. and Rolfe D. W.—Phil. Mag. 37, 863-73, 1946.
8. Patter.—Agri. Eng. 25, 221, 1944.
9. Puri A. N., Crowther and Keen.—J. Agri. Sci. 15, 69, 1925.
10. Puri A. N. and Keen.—J. Agri. Sci. 15, 147, 1925.
11. Sarada Gulvady, Rao K. S., and Rao B. S.—Proc. Ind. Acad. Sci. 229, 25, 1947.
12. Thomas.—Soil Science 11, 409, 1921 ; 1, 1924.
13. Weiser, H. B.—Colloid chemistry, John Wiley & Sons Inc. New York, 1947.
14. Wright C. H.—Soil analysis. Physical and chemical methods. Thomas Murby and Company, London, 1934.