The "Hydraton"-Method, a new Process of Stabilizing Soils by Inorganic Agents

La méthode "Hydraton", nouveau procédé de stabilisation des sols à l'aide d'agents inorganiques

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Summary

A process is described by which permeable soils are changed by addition of chemicals into an impermeable material of unchanged elasticity and plasticity and having the quality of a highly plastic clay. Exact properties of the new stabilizing agent are supplied and its application is described.

Sommaire

Procédé décrivant la transformation de sols perméables, par addition de produits chimiques, en un matériau imperméable d'une étanchéité permanente et offrant les qualités d'une argile plastique. Les propriétés du nouvel agent stabilisateur sont exposées et son application est décrite.

Introduction

In general, natural soils of good stabilizing properties, such as clay and loam or artificial cementations by various methods and types, such as asphalt concrete, bitumen and cement with an addition of plastic material or injections of the latter, are used for the stabilization of soils for foundations and earthworks.

Natural Stabilizing Materials

The use of a natural stabilizing material depends upon sufficient material being available and obtainable at a reasonable cost and without much loss of time. Numerous examples in the past, e.g. the construction of the "Mittellandkanal" in Germany, show, however, that under certain circumstances no expense was considered too great for obtaining the necessary, high-class stabilizing clay for railroad tracks and bridges, even from distances of more than 20 km. The distribution of the natural materials offering the advantage of self-stabilisation is rather scattered, and they are seldom to be found at the particular building site. Apart from this, it is often very inconvenient and difficult to embed the stabilizing material in a uniformly compact manner. It is also doubtful whether the mixing will be perfect, especially in the case of compacting canal banks (*Tode*, 1932; *Gerstenberger*, 1944). The difficulties lie in the exact control of the optimum water content, in the tendency of the soil to change its consistency with changing weather, in the necessarily repeated interruption of the work during rain, in the lack of sufficient protection against rainfalls, and in the necessity of embedding the stabilizing soil in several thin layers, roughening in each instance the underlying bed, which may considerably obstruct the regular progress of the work. The uniform compaction of slopes presents particular difficulties.

In the United States (*Garbotz*, 1949) tests were made to stabilize unsuitable earthwork materials by a treatment with cement and special water-proof cement in a manner similar to that of the soil morter process by means of a concrete mixer; but the tests proved unsuccessful because the essential plasticity and elasticity of the stabilization soon disappeared.

Artificial Stabilizing Materials

Stabilization by means of artificial materials (*Erdmann*, 1952) have been dealt with in detail in literature in numerous publications which cannot all be quoted here. They contain many comparisons with natural stabilizing materials and, by showing the advantages and disadvantages, explain why preference should be given to artificial stabilizations even if, in general, they are more expensive. Bitumen stabilization, for instance, can only be used on dry soil as far as possible gravelly, e.g., in canals.

Principles of the New Process of Stabilization

About two years ago the writer developed a new process which departs from the types of stabilization used so far (*Keil*, 1952a, 1952b). It is a characteristic feature of this process that all cohesive and cohesionless permeable soils of the most varied grain sizes may be changed, by addition of inorganic substances, into a permanent impermeable clay soil of permanent elasticity and plasticity. The process has stood practical tests and a patent is applied for. The process is as follows:

Proceeding from the consideration that less impermeable soils may be improved by addition of very fine-grained materials, because the latter will fill the smallest pores, the idea arose to obtain a good stabilizing material through uniform, mechanical mixing. However, the mixing, either in dry or earthdamp condition, does not guarantee the necessary uniformity; neither does it solve the problem of an economical and rapid placing. If the materials are wetted and then placed in the usual complicated and discontinuous manner, this does not mean a technical progress. Therefore the new process provides for making a thixotropic pulp by means of hydrating, inorganic materials, i.e., in this case, an unstable water-glass of special composition; owing to the high hydration, this pulp has and retains and adhesive, highly hydrophilic character. As the hydration increases, the permeability of the material used, i.e., clay, and in this particular case Na-Bentonite-Montmorillonite, decreases. The thixotropic character facilitates and promotes the mechanical mixing in the concrete mixer of the various materials, such as, sand, finely-ground clay, chemicals and water in desired proportions. However, the thixotropy must give way to hydration as it becomes effective and must be eliminated in fractions of an hour in order to permit the application of the tough soil pulp on slopes in the state of a stiff-plastic mass, which effectively resists sliding.

These requirements are fulfilled by every kind of soil improved by the new process (Fig. 1). In addition to the simultaneous appearance of thixotropy and hydration, a special advantage is the unrestricted possibility of making the stabilizing material, ready for use, in a few minutes, in an ordinary concrete mixer just like concrete. The following figures, obtained in tests, show the success of the new process.

Properties of Soils treated according to the New Process

(1) *Permeability*

Basic Material (Fig. 1)	*Permeability in cm/sec*		*x-Times decrease of Permeability x =*
	Before	*After*	
Weathered loam of mica slate	4.5×10^{-7}	8.0×10^{-10}	562
Weathered loam of gneis	1.0×10^{-6}	1.5×10^{-8}	67
Loess loam	6.3×10^{-6}	9.4×10^{-9}	670
Middle gravelly sand	3.0×10^{-2}	5.6×10^{-9}	roughly 20.000.000

(2) *Percentage of voids.* Weathered loam of mica slate (Fig. 2): 53.6 to 58.0%; Weathered loam of gneis (Fig. 2): 41.8 to 47.1%.

(3) *Moisture content.* Weathered Loam of Mica Slate (Fig. 2): 44 to 50% of dry weight.

(4) *Elasticity.* The modulus of elasticity lies in the range of 10 to 40 kg/cm².

(5) *Shrinkage.* Shrinkage limits from 6.6 to 18.6% equal to the shrinkage limits of normal loams to soft clay.

(6) *Behaviour during continuous stress caused by high water pressure and currents.* The permeability decreases but, contrary to unimproved loam, the structure will not be changed by any of the finest particles being washed-out. Accordingly, the mass is absolutely durable.

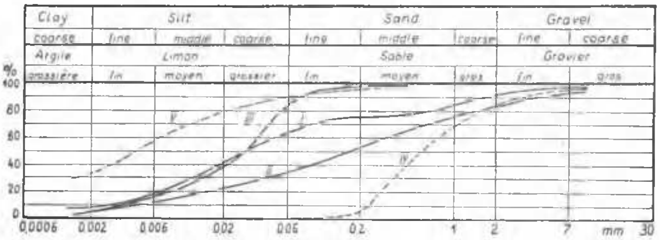

Fig. 1 Grain Size Distribution Curves on Various Kinds of Soil Treated by the New Process and of the Ground Clay Used for the Purpose:
I Weathered Loam of Mica Slate
II Weathered Loam of Gneis
III Loess Loam
IV Fine Gravelly Sand
V Middle Ground Clay
Courbes de distribution granulométrique de divers types de sols traités par le nouveau procédé d'étanchement et de l'argile moulue utilisée à cet effet:
I Limon de phyllite décomposé
II Limon de gneiss décomposé
III Limon de lœss
IV Sable caillouteux moyen
V Argile moulue

(7) *Stability against sliding.* In the type of stabilizing material that has a great porosity, the angles of internal friction are exceptionally great. They are within the limits of gravelly sands and have, without exception, values from 26° to 38°. This is due to hydration, a semi-chemical process, which eliminates the normal laws and relations between water content, grain-size and shearing strength; at the same time, however, they guarantee the permanency by the development of heat. Accordingly, the behaviour of the mixtures does not follow the soil mechanics laws as might be expected from the high water-content, the composition of the grains, and the soft-plastic character.

Fig. 2 Discharge of the Prepared Limit Mix from the Gravity Mixer (Type Jäger)
Déversement du mélange liquide fini hors du malaxeur à chute libre (système Jäger)

Fig. 3 Discharge of the Viscous-Pulpy Mix from the Forced Mixer (Type Kaiser)
Décharge du mélange visqueux pâteux hors du malaxeur-triturateur (système Kaiser)

Fig. 4 The Thixotropically Cohesive Mass is Discharged as a Whole
La masse mi-solidifiée se détache en un bloc cohésif

(8) *Behaviour in regard to subsoil.* On spreading on the subsoil, a boundary reaction takes place which results in a closer contact with the ground surface; therefore, the shearing surface does not coincide with the contact surface but lies in the subsoil.

(9) *Surface energy.* The great surface energy prevents the penetration of water into the mass which, therefore, owing to its weight, expels all water from ditches and sumps and renders them impermeable.

(10) *Submersion resistance.* Tests on submerged specimens showed that in accordance with the composition the materials remain unchanged under water up to a period of months; unimproved loams, on the other hand, are apt to disintegrate more or less in a much shorter period.

(11) *Plasticity.* The thixotropic character makes it impossible to find an exact coefficient for the plasticity of the material, thixotropic pulps passing directly from the liquid into the solid state without plastic stage. If, in spite of this, indices of plasticity of more than 30 were obtained in single tests, this proves that, although the thixotropy is artificial, the plastic qualities were not eliminated.

Practical Application of the Process

Loose, friable, slightly cohesive or cohesionless types of soils such as loess, sandy and lean loam, crushed rock, sand, gravel, rock debris and valley debris, and similar materials whose permeability is not below 1.10^{-7} cm/sec, whose clay contents under 0.002 mm amount to less than 10%, and whose fineness under 0.06 is not above 60% (Fig. 1), that is, all more or less permeable soils are particularly suited for the stabilization procedure.

The mineralogical composition of these soils, i.e., their proportion of naturally present hydrating clay minerals, determines the proportion and the addition of hydration promoting ground clay (Fig. 1) with highly charged, interchangeable ions at the crystal plane. Practice has shown, however, that the amount of the ground clay added, as in Fig. 1, to the different cohesive and cohesionless coarser types of soils is confined within fairly narrow limits; for instance, for loess loam it ranges between $\frac{1}{2}$ and $\frac{2}{3}$ of the amount required in washed gravel sand for obtaining the desired high degree of stabilization. Furthermore, small additions of inorganic chemicals are necessary in order to obtain hydration and thixotropy. This purpose is served by an unstable water-glass of special composition. These materials are well mixed for 2 to 3 minutes in ordinary concrete mixers; in case of slightly more cohesive soils forced mixing machines may be used. After the short period of mixing, the pulpy-liquid mass is discharged (Figs. 2 and 3). It is either transported to the building site or immediately poured out on slopes or into trenches (Figs. 4 to 6) where, having come to rest, it stabilizes at once (Figs. 6 to 8). The mass is subjected to further treatment either mechanically or by hand in order to attain the necessary uniform density and thickness. The placing is in every way the same as in the case of concrete slabs on canal banks or in road construction. Just as the latter, the applied mass must be protected against drying out (Figs. 9 and 10).

Range of Application

The new process makes every building operation independent of the presence of sufficient natural stabilizing material. It may be applied with equal success in sandy regions, free from loam (deserts), and in hilly country, poor in loam—for example dams sites. The quantities of ground clay and chemicals required for stabilizing a material represent no more than a fraction of the total quantity of material. Therefore, its transport to the building site is much cheaper than the transport of all the stabilized material formerly necessary. The building of canals in sandy country is thus considerably facilitated, and the construction of earth dams in comparison with masonry dams in hilly country is likewise rendered much easier than before. However, the great advantage, compared with the former usual placing of natural stabilizing materials, is that the new stabilizing material may be placed uniformly and densely as a whole, without subdividing into sections and without subsequent compaction whereby the laboratory result is, within narrow limits, absolutely assured in practice. The application of only *one* layer of any desired thickness assures the continuous progress of the work and a comparatively large amount of work done, somewhat in the nature of progressive manufacture and comparable with the compaction of American earth dams (*W. Zingg*, 1950). These advantages more than make up for the cost of chemicals and ground clay.

Just as it is usual in the case of concrete constructions, the mixing plant may be erected either at the building site or, in the case of building canals, a portable plant may be used. The stabilizing material flows then direct from the mixer on the top of the slope to the bank itself where it is uniformly applied by finishers. The layer is weather-proof; rain or dry weather do not affect it and cause no interruptions in work. The amount of work may be increased; it depends only on the organisation of the work and the supply of materials. The process was first successfully applied in building the dam "Cranzahl" (Erz-

Fig. 5 On Reaching the Slope the Mass Turns Liquid
La masse se liquéfie en se déversant sur le talus

Fig. 6 Discharge of the Mass on a 1 : 2.5 Slope and Filling of a Ditch. While the Mass Still Flows Down the Spade Stands in the Thixotropically Cohesive Mass
Déversement de la matière étanchante sur un talus d'une inclinaison de 1 : 2,5 et remblayage d'une fosse. Tandis que la matière s'écoule encore, une pelle se maintient debout dans la masse thixotropiquement cohérente

Fig. 7 Filling of the Ditch on the Water-Side Base of the Slope of the "Cranzahl" Dam (Saxony)
Remblayage de la fosse au pied du talus amont du barrage de Cranzahl (Saxe)

Fig. 8 Application of a "Chemical Carpet" of a Thickness of 20 cm on the Water-Side, Slope 1 : 3 at the "Cranzahl" Dam. The Stabilized Mass Stands Vertically Like a Stiff-Plastic Loam
Mise en place d'un «tapis chimique» de 20 cm d'épaisseur sur le talus amont du barrage de Cranzahl, inclinaison de 1 : 3. La matière étanchante se maintient verticalement comme de l'argile plastique

Fig. 9 Application of the Material by Hand—Left Foreground. Right: Freshly Finished Chemical Carpet as a Protection Against Drying-up
Mise en place à la pelle, à gauche au premier plan; à droite: tapis chimique fraîchement appliqué comme moyen de protection contre la dessication

Fig. 10 Survey of the Application of a Chemical Carpet at the "Cranzahl" Dam in Strips of 3–4 m; Left Above the Transport Bridge; in the Foreground Placing Work, at the Back: Finished Chemical Carpet
Vue totale de la mise en place du «tapis chimique» en bandes de 3–4 m au barrage de Cranzahl; à gauche en haut: la voie de transport; au premier plan: la mise en place; au fond: le revêtement chimique terminé

gebirge) in 1950/51 (*Keil*, 1952c, d). Nothing whatever interfered with the progress of the work, not even snow.

The great shearing strength permits the construction of canals, dikes and dams with 1 : 2 slopes on the water side which should be covered with the usual grit layer. The high degree of elasticity and plasticity of the stabilizing material facilitates its use especially in places where a subsidence of the ground is likely to occur, for instance, because of mining operations. For the same reason the method is also useful for stabilisation of the cores of dikes and earth dams and for use in the waterface of masonry dams, because the new stabilizing material follows every settlement without danger (*Lewin*, 1949/50).

Furthermore, the method may be used in earthwork constructions and road-making, for the purpose of stabilizing embankments and cuts exposed to frost and especially for preventing an accumulation of rain water immediately under the top, thus protecting the latter against frost action. The chemicals are distributed directly on the finely broken up ground as in the earth mortar process; the masses are well mixed and the surface is smoothed. Slopes liable to sliding may be secured by completely filling longitudinal ditches on the top edge of the slope with the new material, thus preventing the inflow of dangerous surface water, or by making—like stone insert—a lattice-like diagonal reinforcement in the slopes according to the method.

In foundation engineering the method is suited for stabilisation of the base and for protection of the foundation against soil moisture as well as for stabilisation and filling of sumps.

Conclusion

By means of the new method the engineer may change any soil unsuitable for his purpose into an excellent stabilizing material through a small addition of hydrating and stabilizing inorganic chemicals. The material obtained is superior to every kind of clay soil as to endurance and safety against washing-out.

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