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Influence of Hydrating Chemical on Rheological Properties of Fine-Grained Soils

Influence de substances chimiques hydratantes sur les propriétés rhéologiques des sols à grains fins

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Summary

The authors describe how the stability of fine-grained soils can be increased within the liquid zone by adding clays and hydrating chemicals to increase their load bearing capacity.

Both the stability and density of such soils are greatly improved, together with high compressive strength ; shear strength is also increased. The favourable geotechnical influence exerted on the rheological properties is due to the interaction of surface tension between the clay and the special hydrating chemicals. By exchanging ions, which exist only on the surface of clay, these chemicals promote absorption of water around the clay particles.

In any calculation of the stabilization thus achieved, the quality of the clay and the grading of the grain sizes of the soil play on essential part.

The most intensive stabilizing effect of hydration will occur in soils having the finest grains.

Sommaire

La présente communication donne pour la première fois des résultats de recherches détaillées sur la possibilité d'augmenter la stabilité des sols à grain fin, qui se trouvent près de la limite de liquidité, par produits chimiques hydratants additionnés de vraies argiles, afin d'obtenir des qualités géotechniques spécialement importantes pour la construction.

En particulier l'auteur prouve dans cet article que la compacité et la stabilité d'un sol traité de cette façon sont essentiellement améliorées et surtout que sa cohésion vraie se trouve augmentée. On obtient ainsi une augmentation notable de la résistance au cisaillement, bien que le système se trouve sensiblement plus près de la limite de liquidité que le sol avant traitement. L'amélioration des propriétés rhéologiques est due aux efforts combinés des forces superficielles physico-chimiques de vrais minéraux argileux avec certaines additions chimiques hydratantes. Celles-ci causent par l'échange des ions se trouvant seulement sur les surfaces des minéraux argileux une attractive absorption solide d'eau de ces minéraux argileux.

La qualité des argiles et la composition granulométrique des sols jouent un rôle essentiel dans la détermination quantitative de la stabilisation obtenue du mélange. Plus la surface spécifique des sols est grande, c'est-à-dire plus ceux-ci sont à grain fin, plus l'effet stabilisant de l'hydratation est intense.

Plusieurs diagrammes illustrent clairement l'influence de cette stabilisation par comparaison avec des sols non améliorés et montrent exactement dans quelle proportion l'effet d'hydratation améliore les propriétés rhéologiques.

The authors show how a soil improved by the addition of hydrating chemicals has its stability, shear strength and density increased. Its resistance to erosion, as compared with impervious substances like clay, is fully guaranteed.

Research undertaken so far has been limited to stabilization by the addition of lime, cement, bitumen, artificial resins and other substances. The aim has been to prevent water from upsetting the mechanical properties of soil.

The authors describe a soil stabilizing process based on hydration, which stabilizes various soils having such a high moisture content that without the addition of hydrating chemicals they would be reduced to a liquid state. The chemicals employed are water-glass, K_2CO_3 and Na_2CO_3. The shear strength and the water resistant properties of natural and improved soils are compared, the hydration effect being expressed as a value of maximum compressive strength. In spite of the high plasticity when compared with untreated soils, the shear strength is very high and remains constant with increasing moisture content. This property is of outstanding advantage in hydraulic engineering applications.

The stabilization process consists of mixing the soils with the appropriate chemicals in a concrete mixer and adding water. As a result of hydration, the very short liquefying process initiates a thixotropic stiffness. During this process, the surface forces on the clay particles attract and finaly absorb the water molecules, in exchange for ions or ion groups. The colloïdal particles of water glass increase stability. The strength imparted to the soil is quite independent of its varying moisture content, since the water is present in a "semi-solid" condition owing to the hydration process.

Moisture content may vary from 0·20 to 0·40. The varying water-absorbing capacity of the mixture of natural soil and clay without a chemical additive depends upon the degree of porosity, the grain size, the specific surface, and the mineral and chemical properties of the smallest particles. The addition of chemicals enlarges the "limiting area" of the water content in comparison with the untreated mixture, with causing any change of consistency and shear strength. The greater the specific surface of the basic material, and the higher the liquid limit of the clay, the greater will be the water resistant capacity. The reason for the comparatively high shear strength and its permanence, as well as the prevention of the liquid state in contrast to intreated soils, depends upon an exothermic water binding process. This is comparable with the heat given off during the setting of concrete, although the intensity of heat in the latter case is much lower, whereby the plastic state is brought about. The behaviour of a treated mixture of natural soil with clay is determined in an undrained test from the following equation :

$$\tau_b = c + (\sigma - pw) \tan \varphi$$

In this test the effect is similar to that of a suddenly applied maximum load, the water content being within the limits of a liquid state. Assuming that the moisture content is 0·36, the shear strength of a treated sample will be at least 0·10 kg. per sq. cm. and the angle of shear resistance will be such that tan φ is nearly equal to zero.

An impervious layer of weathered loam or clay in a liquid state, or with a moisture content of 0·30, will produce a negative result under the same test conditions; the above values will be sero. Chemical treatment exerts a substantial influence on the rheological properties in what is known as the "sedimentary state".

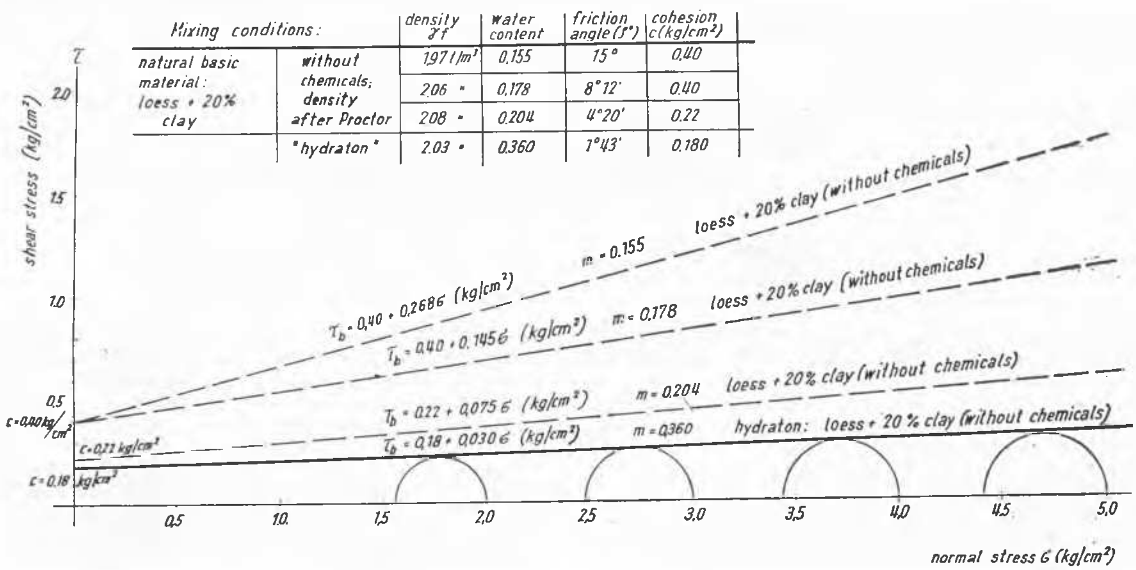
If the soil sample is loaded, gradual consolidation will take place and the values of compressive strength and friction will steadily increase.

Using a standard Proctor apparatus, the optimum dry density $\gamma p = 1{\cdot}75$ tons per cubic metre, and the optimum water content of the mixture of natural basic material and clay (loess with 20 per cent clay having a liquid limit of 0·80), were determined in several tests on samples of untreated material. The shear strengths of the various untreated mixture with moisture contents of 0·155, 0·178 and 0·204 respectively are shown in Fig. 1. These show a sharp fall in strength with increasing moisture content, and the shear strength of weathered loess with a 20 per cent addition of highly plastic clay varies from $\tau_b = 0{\cdot}40 + 0{\cdot}268\ \sigma$ at a moisture content of 0·155 to $\tau_b = 0{\cdot}22 + 0{\cdot}075\sigma$ at a moisture content of 0·204. According to Fig. 2, the latter is greater than the plastic limit which is 0·187·

Using this undrained test, the true angle of internal friction is 4 deg. 20 minutes and the compressive strength is 0·22 kg per sq. cm. With a untreated mixture of loam and clay having a moisture content of 0·32, the shear strength is zero. A comparison with an untreated mixture of soil and clay, having a moisture content of 0·36, shows the shear strength $\tau_b = 0{\cdot}18 + 0{\cdot}030\sigma$, corresponding to an angle of internal friction of $\varphi = 1$ deg. 43 minutes and a compressive strength of 0·18 kg per sq. cm.

In Fig. 2 the shear strengths of untreated mixtures of soil and clay (weathered loess with 20 per cent of clay added, with a liquid limit of 0·80, and optimum moisture content), obtained from an undrained test, are compared with these of treated soil samples. The optimum moisture content is 0·178 and this is slightly below the saturation line. If the moisture content is slightly increased, the shear strength of the untreated mixture of soil and clay will decrease very rapidly. The saturation limited is reached simultaneously, and the sample of untreated soil will lose its stability.

The moisture content and the Atterberg limit of the untreated mixture are in marked contrast to the saturation limit of the treated material. The shear strength derived from undrained tests is given in the lower part of Fig. 2, assuming that there is a constant load of 1 kg per sq. cm. The stability and permeability coefficient, of natural, impervious soils like



Mixing conditions:		density γf	water content	friction angle ($\varphi°$)	cohesion c(kg/cm²)
natural basic material: loess + 20% clay	without chemicals; density after Proctor	1.97 t/m³	0.155	15°	0.40
		2.06 "	0.178	8°12'	0.40
		2.08 "	0.204	4°20'	0.22
	"hydraton"	2.03 "	0.360	1°43'	0.180

Fig. 1 Comparative tests of chemically treated soil samples with untreated samples having different moisture contents indrained shear test (traixial test).

Friction angles and cohesion values at increasing moisture content according to (3) (Natural basic material : loess + 20 per cent of highly plastic clay, $PL = 0{\cdot}80$).

Essais triaxaux comparatifs sur échantillons de sol amélioré par traitement chimique et de sol non traité. (Angles de frottement et cohésion pour des valeurs croissantes de teneur en eau. Mélange de base limon plus 20 pour cent d'argile fortement plastique $PL = 0{,}80$).

loam and clay is closely linked with the optimum moisture content, as compared with chemically treated soil samples.

When using a treated mixture, the optimum moisture content of 0·42 is increased far beyond the liquid limit of 0·289, owing to the water binding capacity of the hydration process. Thus the value of this treated mixture is increased about 2·1/2 times that of a soil with optimum moisture content as given by Proctor. Since the treated mixture has a moisture content greater than the liquid limit, there can be no air within the void space of the soil sample. An undrained test revealed a shear strength of $\tau_b = 0{\cdot}18 + 0{\cdot}03\sigma$, although with a moisture content of 0·36, complete saturation of the treated mixture could be expected. The moist density is $\gamma_f = 2{\cdot}03$ tons per cub.m., whereas the dry density is $\gamma_p = 1{\cdot}75$ tons per cub.m. Undrained tests on untreated mixtures of soil and clay (loess with a 20 per cent addition of clay and a plastic limit of 0·80); showed neither shear strength nor compressive strength (Fig. 2). With untreated impervious strata of loam and clay, shear strength and compressive strength cannot be obtained with such a high moisture content. (Fig. 3.)

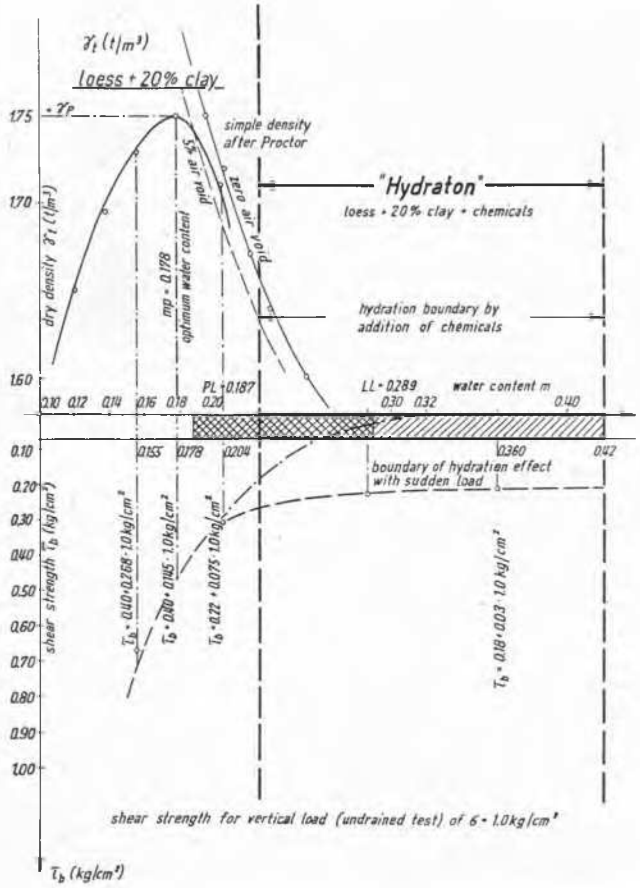


Fig. 2 Comparative graph showing the change of shear strength values of an untreated soil sample (moisture content after Proctor) and a chemically stabilized sample. (Enlargement of the hydration boundary by addition of chemicals).

Graphiques comparés montrant la modification du taux de cisaillement entre un échantillon de sol non traité (teneur en eau après Proctor) et un échantillon de sol stabilisé chimiquement (élargissement du domaine d'hydratation à la suite de l'addition des produits chimiques).

Measureable compressive strength on unconsolidated samples is due only to the hydration effect of chemical additives Such compressive strengths at high moisture content are completely missing in loam and clay. Chemically treated soil has a shear strength as compared with untreated soil, in spite of the high moisture content. In Fig. 3 (a) and 3 (b) comparisons are made between various treated mixtures, which include gravel and weathered loess with different additions of clay. The addition of chemicals, whilst retaining the high moisture content resulting from the hydration effect, causes a reduced consistency to one lying between a semi-solid and a soft plastic material. The true compressive strength is determined by the intensity of hydration.

In conclusion the rheological properties of all fine-grained and coarse soils can be improved, in spite of high moisture content, by a 5 per cent addition of water glass with small additions of a water soluble univalent salt and a corresponding amount of hydrating clay with a plastic limit of 0·50. The liquid state of chemically treated soils is considerably limited, and the shear strength, resistance to erosion and density are raised.

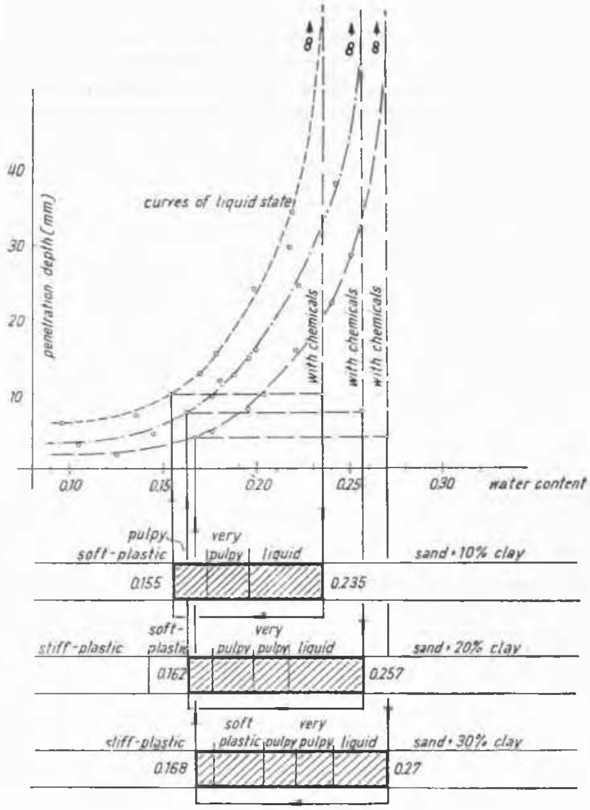


Fig. 3 a The influence of chemical additives and reduction of consistency to a soft plastic state on a mixture of sand and clay in liquid state (liquid limit of the clay = 0·80), while retaining a high moisture content, as a measure for the hydration process according to (3).

Grâce au traitement chimique, obtention d'un état moyennement plastique avec un mélange de sable et d'argile à l'état de liquidité (limite de liquidité de l'argile 0,80) avec une teneur en eau augmentée par l'effet du phénomène d'hydratation.

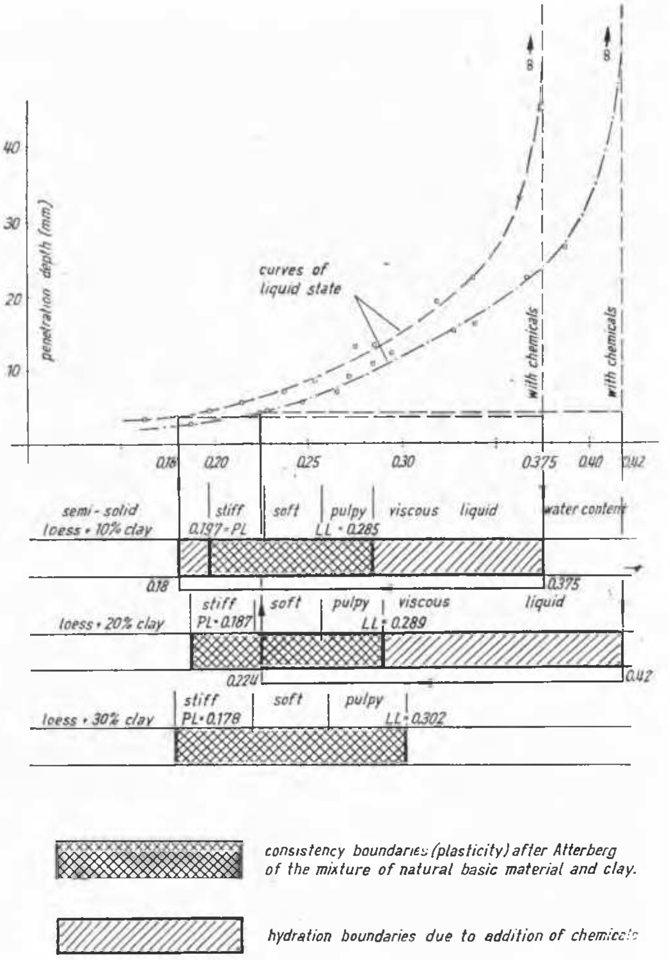


Fig. 3 b The influence of chemical additives and consistency reduction to a soft plastic state on a mixture of loess and clay in liquid state (liquid limit of the clay = 0,80), while retaining a high moisture content, as a measure for the hydration process according to (3).

Grâce au traitement chimique, obtention d'un état moyennement plastique avec un mélange de limon et d'argile à l'état de liquidité (limite de liquidité de l'argile 0,80) avec une teneur en eau augmentée par l'effet du phénomène d'hydratation.

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