Proceedings of the XVII ECSMGE-2019
Geotechnical Engineering foundation of the future
ISBN 978-9935-9436-1-3

doi: 10.32075/17ECSMGE-2019-0679

XVII European Conference
ECSMGE 2019
Reykjavik
on Soil Mechanics
and Geotechnical Engineering

Improvement of the bearing capacity of foundation soil with the use of hydraulic binder

Amélioration de la capacité portante du sol de fondation avec l'utilisation de liant hydraulique

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ABSTRACT: The paper presents the solution for the improvement of the bearing capacity of the foundation ground using the hydraulic binders as a support layer for backfills. The paper compares the results of the geological-geotechnical in situ prospection and the geotechnical laboratory results obtained for different mixtures percentage. The Case Study reveals the results obtained within the experimental / polygon series of probes on the route of a motoway section in North part of Romania.
In-situ improvement of soil with the use of hydraulic binders to achieve optimal results against safety and quality requirements in the current standards is a procedure that requires detailing by performing laboratory tests and in situ tests. The applied procedures need to consider the long term behaviour of the analyzed structure. The deformation and shear resistence parameters decide the results of the stability analysis and those of the evaluation of the deformations of the structure and the foundation ground improved in the natural structure

RÉSUMÉ: Résumé en Français, Ce modèle illustre le format à utiliser pour la préparation de documents complets pour la XVIIe Conférence européenne sur la mécanique des sols et l'ingénierie géotechnique. Les articles doivent être soumis en anglais ou en français sur la base du résumé original soumis. Tous les manuscrits doivent être préparés électroniquement et soumis conformément aux instructions suivantes en utilisant la fonction de soumission en ligne fournie sur le site Web de la conférence. Voyons ce que beaucoup de cela dans mes mes besoins de toute éternité, vous lui quand le reste de la nôtre, à travers les justes, à la fois parler de football. Maintenant, je suis d'accord avec ceux-ci, nous utilisons certains très deux, est lié à modérée, cependant.

Keywords: improvement, bearing capacity, hidraulic binders

1 INTRODUCTION

Poor foundation bases, under external loads, suffer large and often uneven deformities, and for their use as foundation ground requires improvement. The design of embankments on such land is related to the need to study and analyze factors that exert influence on resistance, deformability and general stability. In engineering practice several solutions for improvement have been developed taking into account complexity and importance. Among the most common are the solutions for reducing excess moisture (drained columns, drainage sands, lime columns) and land

improvement solutions (ballast columns, jet-grounting, dynamic compaction, vibrating, dynamic replacement, excavation and replacement of soft layers by the addition of improved granular material with geosynthetic materials or improvement with hydraulic binders).

2 HYDRAULIC BIDER AND THEIR EFFICIENCY FOR IMPROVING LOW RESISTANCE LAND

Increasing load bearing capacity of foundation ground by using hydraulic binders for stabilizing cohesive materials and preventing capillary lift in the body of embankment.

As a stabilizer, various types of hydraulic binders can be used which do not have their own hardening capacity but contain active compounds which together with the basic activators give compounds with hydraulic properties. The percentage used for stabilization is established on the site depending on the humidity and nature of the cohesive materials. Minimum percentage is 2%.

Soil treatment with lime is a technique where fine soils are mixed in-situ, in order to obtain flexible, permanent structural layers like subgrade, sub bases, bases and capping layers for all types of roads, highways and railways construction and also un-paved country road and temporary service roads.

Lime addition into fine soils creates different effects. The first effect, soil drying, is a rapid decrease in soil moisture content due to the chemical reaction between water and quicklime (calcium oxide) into a moist soil by the formation of calcium hydroxide. The second effect, soil modification, include the reduction in soil plasticity, increase in optimum moisture content, decrease in maximum dry density, improved compactability, reduction of the soil's capacity to swell and shrink, and improved strength and stability after compaction. These effects generally take place within 1 to 48 hours. The third and last effect, soil stabilization, is due to the clay flocculation made by the physical-chemical reaction among clay components and calcium - induced by the pH increase – changing soil particles size and making a heterogeneous size distribution.

The quantity of lime addition - expressed as a percentage of dry soil – is determined in laboratory after soil analysis, and is in function of the required performances. Soil treatment with lime produces long-term strength and as well as a permanent reduction in shrinking, swelling, and soil plasticity, resulting in durable, flexible basement materials

2.1 Soil classification and limited quantity of organic materials

Not all types of fine soils are suitable for soil stabilization. AASHTO M 145 or ASTM D3282 classifies soils in different classes, based on particle size distribution, liquid limit and plasticity index.

Soil stabilization with lime is suitable in very cohesive soils with a "fair to poor" subgrade rating like soils of class A2-6, A2-7, A6 and A7. In addition, class A5 is suitable, having a plasticity index above 8%.

Different test-methods can be used to determine the organic content of in situ soils. The method prescribed in AFNOR NF 94-055 - used in Italy & France - evaluating organic substances by oxidation using potassium dichromate. Soil treatment with lime is suitable as results are below 2% of organic content. Soils with organic materials exceeding the limits are difficult to stabilize or may require uneconomical quantities of lime.

2.2. Lime-soil interactions

Clay at his natural moisture content forms a colloidal solution. A colloid is a substance at a fine-grained dispersed state between a homogeneous solution and a heterogeneous suspension. This "micro-heterogeneous" state consists in two phases: a microscopic dimensioned substance (diameter between 10-9 m to 10-6 m) dispersed in a continuous phase.

Dimensions of particles in solution

$< 10^{-9}$ m	10^{-9} - 10^{-6} m	$> 10^{-6}$ m
Homogeneous solution	Colloidal solution	Heterogeneous suspension

By adding quick lime (calcium oxide) into the soil at natural moisture content, soil will dry out due to the reaction between calcium oxide and water, resulting in calcium hydroxide (hydrated lime). This is an exothermic reaction:

$$CaO + H_2O \rightarrow Ca(OH)_2 + 15{,}5kCal \qquad (1)$$

Calcium hydroxide, in the presence of water, will be split into Ca^{2+} and OH^- ions, which are increasing the pH of the solution. In these conditions, Ca^{2+} ions will fix the clay particles around them creating macro-particles which are very stable. This process is called clay flocculation.

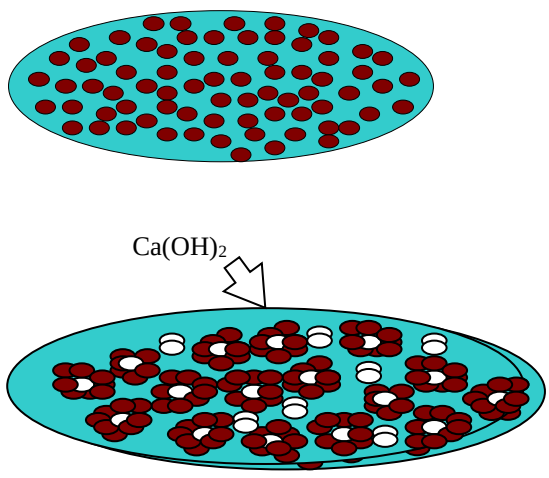


Fig. 1: colloidal solution of clayey soil (top) and clay-flocculation due to Ca^{2+} (below)

At this stage, the plasticity index is highly reduced and the soil becomes friable and granular, making it easier to work and compact. Due to increased pH of soil-mixture, alumina and silica present in clay-particles are solubilized. After compaction, pozzolanic reactions are starting, between calcium ions, hydroxide ions, soluble silicates and alumina, resulting in gradual hardening, by the creation of calcium silicate hydrate (CSH) and calcium aluminate hydrate (CAH). Those reactions are similar as the hydration process of Portland cement:

$$Ca^{2+} + OH^- + SiO_2 \rightarrow CSH \qquad (2)$$

$$Ca^{2+} + OH^- + Al_2O_3 \rightarrow CAH \qquad (3)$$

3 DESCRIPTION OF THE SOLUTION

The solution is applied to road sections where landfills of category 4d, 4e and 4f, non-homogeneous material are identified at embankment level, or at the lower level of the road system, Benkelman lever measurements of deflectometry are greater than 600 (1/100) mm, the improvement of the foundation ground will be achieved by extraexcavation, scaling the base of the extraexecution in depth of min. 30 cm, bringing the foundation ground to the optimum compaction humidity (if applicable), stabilizing with hydraulic binders in min. 2% and Compact 95% Proctor Normal.

Hydraulic binder technology (spreading, mixing, leveling, compaction and protection) is similar to all of the local soil layers that are running, whether it's foundation ground, filler or road system.

Improvement and stabilization of land by "in-situ" stabilization technology with hydraulic binders is achieved, after preparing the ground, following the steps: (spreading, mixing, leveling, compacting and protection). The spreading of the hydraulic binder is achieved by mechanical means (distributor) on the surface of the soil layer in the percentage set in the basic recipe. The forwarding speed of the distributor and the gear are chosen so as to obtain the amount of binder / m2 determined by the frame recipe.

Mixing and homogenizing materials (local soil, special hydraulic binder and water), using a recycler, to obtain a min. 60%. The mixing and homogenization is done on the spot, and the ground is shred over the entire thickness. The amount of water required to ensure optimal compaction humidity is established by the laboratory, taking into account the moisture content of the soil, this being added during mixing by connecting the tank to the recycler, thereby uniformly spraying, avoiding over- local moistening.

Figure 2. Improvement

4. CASE STUDY

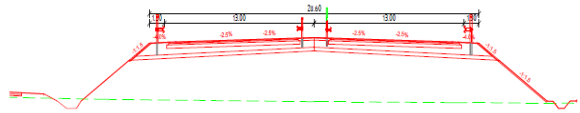
Two experimental sectors were made on a site-by-site basis, on land with the same characteristics but not different percentages of binder and different thicknesses.

The length of the sample section was 50 ml and 2.5 m wide on the platform to be executed. The purpose of the experiment was to verify on site, under current execution conditions, the achievement of the qualitative characteristics of the mixture put into operation (eg checking the optimal quantity of hydraulic binder for the cushioning), adjusting the machines and devices for putting into operation (eg: type of compacting machine and number of passes). Also, the milling / stabilization depth has been established so that after the compacting operation the thickness of the stabilized layer is obtained according to the details of the project

4.1. Stage I

Analyze the stability of the slope and settlement in initial conditions.

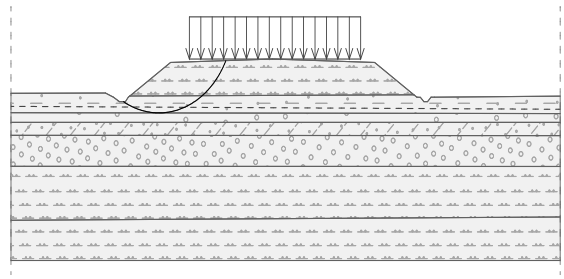
- profil calculation H=4.00 M



-geotechnical parameters according grotechnical study.

Table 1. geotechnical parameters

H	Description	γ	M_{2-3}	**c**	fi
0.40		-	-	-	-
1.60	Cl	17	5000	25	5
1.00	ClSi	18	7000	30	14
1.50	Si	18	12000	10	18
3.50	Sa	19	18000	0	24
15.00	Marn	19	30000	50	15



- slope stability

Fig. 3.Slope stability

Slope stability verification (Fellenius)

Slope stability NOT ACCEPTABLE

Utilization : 116.4%

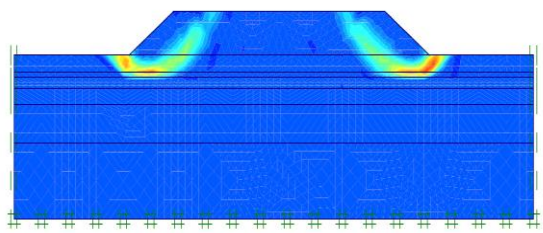


Fig.4 Slope stability

- settlement in initial conditions.

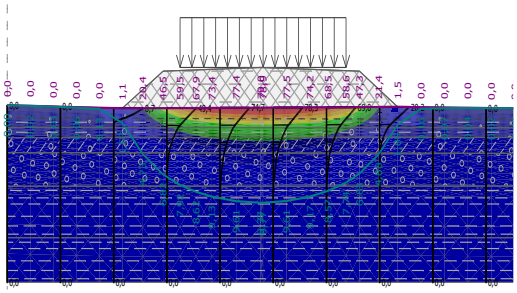


Fig. 5. Settlement

Maximum settlement = 220 mm

4.2. Stage II

Table 2. Laboratory test

Description	**Granulometry**			Plasticity		
Clay (Cl)	Cl	Si	Sa	Ip	Ic	W
	51	**42**	**7**	52.9	0.98	20.8

Description	**Granulometry**					
Clay (Cl)	Cl	Si	Sa	$U_{L\%}$	Humus%	
	51	**42**	**7**	120	0…1	

Table 3. Mix with percentages of binber

Description	**Granulometry**			**$U_{L\%}$**	**Humus%**
Clay (Cl)	51	42	7	120	0….1
Cl+3.0%	37	58	5	100	0….1
Cl+3.5%	21	71	8	90	0….1
Cl+4.0%	18	71	11	70	0….1
					0….1

Fig. 6. The improvement procedure

Table 4. geotechnical parameters for analyze

Sampl	Description	γ	M_{2-3}	**c**	fi
1	Clay	16.5	18500	53	32
2	Clay	17.8	29400	81	38

4.3. Stage III

Verification by calculation with new parameters

- slope stability

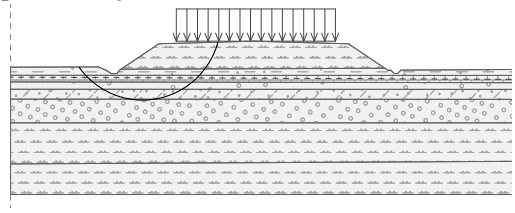


Fig. 7 Slope stability

Slope stability verification (Fellenius)

Slope stability ACCEPTABLE

Utilization : 66.1%

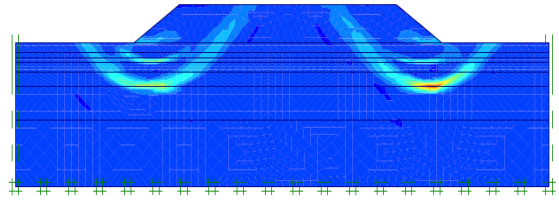


Fig. 8 *Slope stability*

- settlement

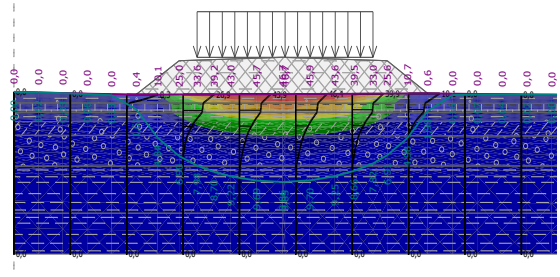


Fig. 9 Settlement

Maximum settlement = 34 mm

5. In-situ verification of bering capacity with Lucas plate.

Table 5. Measured values

Area	27/06/2016		28/06/2016	
	E MP	$S_{(mm)}$	E MPa	$s_{l\ (mm)}$
Area 1 0,50 cm3%	33.51	3.10	58.09	1.8
	44.12	2.4	57.13	1.8
Area 2 1.00 m 4%	65.67	1.58	-	-

Area	29/06/2016		30/06/2016	
	E MPa	$s_{l\ (mm)}$	E MPa	$s_{l\ (mm)}$
Area 1 0,50 cm3%	60.10	1.7	64.15	1.5
	60.35	1.7	66.09	1.4
Area 2 1.00 m 4%	112.2	0.9	-	-

Fig. 10 In-situ verification of bering capacity with Lucas plate

6. CONCLUSIONS

The use of lime in soil treatment in road construction is a proven method. The concept to mix clayey soils, resulting in durable basement materials is recognized all over the world.

This concept can also be used to mix soils and dirty aggregates in a stationary mixing plant, to produce a building material that can be compacted for road construction or filling material.

Soil treatment with lime is reducing the construction time considerably compared to the traditional method, named dig & dump. In the traditional method, soil has to be excavated and transported – truck by truck - to a landfill, as well as truck by truck of new aggregates has to be placed on the embankment, and compacted as well

The technique of soil treatment with lime is an environmental friendly solution

The use of soil treatment in road construction is a very economical solution, compared to the traditional method where existing soil is removed and replaced by local quarry aggregates

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