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Impact of the soil-stabilization with lime

Impact de la stabilisation des sols à la chaux

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ABSTRACT: The protection of environment and economical consideration demands giving the usage of internal soils preference over external materials. Soil-stabilization with lime increase the bearing capacity and treats the properties of cohesive soils due to chemical reactions. During a soil-stabilization with lime, the Ca2+ ions introduced into the soil attach to the surface of the clay particles, replacing the cations located there previously. Due to the high charging of the Ca2+ ions, the clay particles coagulate. The coagulation exerts a decisive effect on the soil structure, resulting the plasticity index in a shifting towards a certain zone. This effect leads to the elimination of the silt and clay particles, resulting in an intensive reduction surface of the particle of the stabilizations. Due to the coagulating particles, the friction angle increases, and also the value of cohesion becomes higher. The addition of lime results consequently in a growth of the compression strength of the soil, leading to an increased load bearing capacity. In order to define the internal friction angle (Φ) and the cohesion (c), triaxial compression test were done with ten different kind of soils. The soil-stabilization with lime were made with 2 %, 4 %, and 6% additional lime, the temporal aspect has been investigated in ages of 1, 7, and 28 days. In case of admixing an ideal quantity of lime, the soils are shifting towards the value of Φ=40o. The extent of growth of the cohesion did not show as clear tendency as the friction angle, but give back a significant increasing.Contrary to the literature, I regard to remark that the positive impacts of soil-stabilization with lime is basically a result of the cation exchange, while the puzzolan reaction playing only a secondary role. It is also important to remark that the lime stabilization of soils is not only suitable for the drying up of soaked soils. With the application of a planned and properly executed stabilization, load bearing capacity of ballast materials can be achieved with local soils regarded or qualified as unsuitable. Accordingly, the ballast and pavement layers can be effectively reduced, and the quantity of delivered external materials minimized.

RÉSUMÉ : Les considérations environnementales et économiques font préférer l'utilisation des matériaux locaux aux matériaux extérieurs transportés sur place. Avec ses processus chimiques, la stabilisation des sols à la chaux permet une augmentation de la portance des sols argileux et une améliore de leurs propriétés. Lors des processus de stabilisation, les ions Ca2+ remplacent les cations qui s'attachent à la surface des grains d'argile. Les grains d'argile s'agglomèrent à cause de la haute charge des ions Ca2+. L'agglomération provoque un changement important dans la structure du sol et, en conséquence, l'indice de plasticité du sol se décale vers une certaine zone. Cet effet élimine les grains d'argile et de limon diminuant ainsi radicalement la surface des grains du sol stabilisé. À cause de l'agglomération des grains, les valeurs de l'angle de frottement interne et de la cohésion augmentent. En ajoutant de la chaux, la compressibilité des sols diminue, en conséquence la portance des sols augmente. Afin d'établir le changement des valeurs de l'angle de frottement interne (Φ) et de la cohésion (c) nous avons effectué des essais triaxiaux sur différents sols. Nous avons stabilisé les sols en ajoutant 2%, 4% et 6% de chaux et nous avons mesuré l'effet du temps avec des essais effectués à l'âge de 1 jour, 7 jours et 28 jours. Dans le cas d'une addition de quantité optimale de chaux la valeur de l'angle de frottement interne est de 40°. Dans le cas de la cohésion, il a été impossible de démontrer une tendance, mais une augmentation importante a pu être observée dans tous les cas. Contrairement à la bibliographie technique sur les essais lors de la stabilisation des sols à la chaux, l'agglomération causée par l'échange de cations a un rôle dominant, tandis que les réactions pouzzolanes ont plutôt un rôle secondaire. Il est important de souligner également que la stabilisation des sols à la chaux n'a pas pour seule application le séchage des sols mouillés ou humidifiés. En utilisant une formule bien établie, une portance équivalente au gravier peut être atteinte avec les sols locaux, ainsi les sols locaux qualifiés de non-utilisables peuvent être finalement convenables pour la construction routière. En conséquence l'épaisseur de l'assises de chaussée et celle de la structure de la chaussée peuvent être diminuées efficacement, et la quantité des matériaux extérieurs transportés peut être minimisée.

KEYWORDS: soil stabilization with lime, cation exchange, bearing capacity

1 INTRODUCTION

The road vehicle and railway traffic are increasing worldwide that require a permanent extension of the infrastructure. In addition to the extension, the high load bearing and economical operation are required in new infrastructure and rehabilitation investments. To satisfy the above demands, the expectation towards pavements, bedding and subsoil is increasing continuously. Similar tendencies can also be experienced at industrial and commercial buildings e.g. their industrial floors, service-roads and parking area.

According to the Hungarian code (ÚT 2-1-222-2002), the above high requirements can essentially be satisfied by granular soils; the application of transient and cohesive soils are limited. Another argument prevailing against the use of locally transient and cohesive soils is the fact that their characteristics are extraordinarily influenced by rainfall: their workability is decreasing rapidly and their load bearing capacity becomes practically zero. Consequently, they may upset a strict time schedule due to the drastically abbreviated execution times, so their application result significant risks.

The omission of local materials and the delivery and use of extraneous ones arises questions related not only to costs but also to environment protection and to the preservation of national property. The excavation of extraneous materials cause damages on nature, and the transportation of thousands and millions m^3 of materials to infrastructure and industrial plants also results considerable load to the environment. Beyond the above effects, this significant transportation also abrades, damages and amortizes the already existing infrastructure.

2 GENERALLY ABOUT THE SOIL-STABILIZATION WITH LIME

The soil-stabilization with lime is a successful and widespread procedure for several decades in the USA and Western Europe, while this technology is applied in Hungary and in the neighboring countries only for the drying of sodden earthworks. The research work was performed with Hungarian soils, with the aim of supporting the work of designers and contractors to use local soils as high bearing capacity layer and to reduce the thickness of bedding and floors.

Mainly cohesive soils are used to be stabilized with lime, however transient and clayey silty gravely soils can be stabilized satisfactory based on my research. Therefore I modified a figure of a generally used literature (Mitchell &, Hooper, 1961.) about the types of suitable soils for stabilization with lime with the modern machineries.

My suggestion based on my laboratory tests and field experience is shown in red in Figure 1.

The stabilized layer can be built of materials mixed in situ or at a distant site, however the soil is generally not moved but worked in at the location of its original place, transforming it into a layer of sufficient load bearing capacity. Bedding and pavement layers are built on to the stabilized layer to achieve the full layer system of a road, runway or industrial floor. However in case of roads exposed to a lower traffic, forestry or agriculture roads, the stabilized layer may also used as pavement.

During the construction of the stabilized layer, the required quantity of lime is spread over the previously executed surface by a truck provided with a dosing head. The quantity of the lime is 8-60 kg/m^2 depending on the thickness of stabilization and on the type of soil. Subsequently the soil is mixed with the lime by a remix machine. In case the process of stabilization requires water, the modern remix machinery is able to add water through the mixing head. Following mixing, the layer is compacted, and the required ground level provided.

The lime improves the soil characteristics through chemical reactions. Chemical reactions start with the mixing and may take several decades. The chemical reactions during the soil stabilization with lime are as follows:

- dissolution of the lime – reduction of the water content;
- cation exchange-coagulation;
- puzzolan reaction-cementation;
- carbonatization – development of limestone.

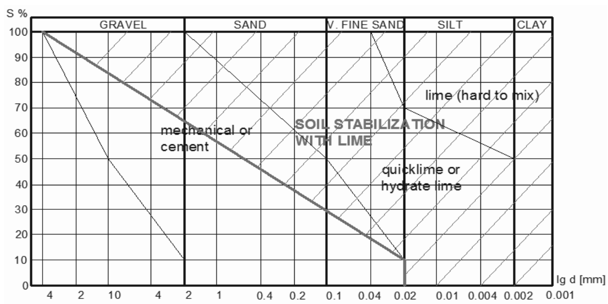

Figure 1. Delimitation of grain size distribution areas from the point of view of soil-stabilization with lime (Kézdi, 1967., Szendefy, 2008.)

3 DELINEATION OF MY RESEARCH

During the research 21 soils were measured in the laboratory of Budapest University of Technology and Economics. The origin soil properties of the measured soils are listed in the Table 1. For the verification of the laboratory tests some in-situ stabilization were analyzed as well.

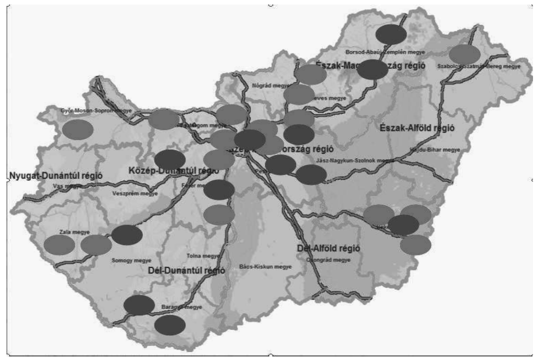

Figure 2. Red spots show the origin of the soils for laboratory measurements, blue spots show in-situ bearing measurements

After the literature 2, 4, 6% quick lime was added for the soils. The quantity of the lime is the percent of the dried soil. Some measurements was done with hydrate lime as well, but the final determinations are given in quick lime, because it contains only the agent (CaO), which is the unit of necessary active agent

My laboratory and field work included soil mechanics parameters (plasticity, grain size, permeability, Proctor-test, swelling), bearing capacity measurements (triaxial compression test, CBR test, durability test) and geological tests (X-ray, derivatograph, pH).

The soils were dried to the laboratory air humidity, than were determined their moisture content and were determined the quantity of the added lime. The lime and the required water were mixed during 15 minutes than left it rest 45 minutes. After resting they were remixed and compacted with Proctor-machine. After compaction the mixtures were left for curing in waterproof package.

To measure the time effect of soil-stabilization with lime I made measurements 1 hour, 1 day, 3 days, 7 days, 14 days and 31 days after compaction.

I can show only a part of my research because the compass of the article.

4 ALTERATION OF THE SOIL STRUCTURE

The clue of soil-stabilization with lime is an alteration of the structure of soil caused by lime. Through the admission of lime, the cohesive soils become crumbly, characterized by a reduced plasticity.

4.1. *Alteration of plasticity*

Several researchers pointed out that the plasticity index of soils decreases even if a very low quantity of lime is added (Wang, 1963., Jan, & Walker, 1963., Kézdi,1967., Nemesdy, 1983.)

They explain the reduction of the plasticity index with a slight reduction of the liquid limit and with the drastic increase of the plastic limit.

As I saw the clue of stabilization in the alteration of the soil structure, I have performed experiments to find the exact mechanism of changes of the plasticity index, and processed literature data.

During the experiments, several soil types were tested (Ip = 6.4 - 69.2 %), admixing 2 % - 4 % - 6 % of lime at different ages.

Table 1. Origin soil physics parameters

Sign of soil	Plasticity index [%]	Grain size < 0.1mm [%]	Friction angle [°]	Cohesion [kPa]
T1	22,0	88,4	10.5	61.7
T2	18,5	76,6	22.4	88.3
T3	50,0	96,4	11.9	117
T4	12,3	87,6	25.6	72.9
T5	33,5	98,7	11.4	37.6
T6	61,5	99,3	18.2	123
T7	43,4	98,8	22.8	114.8
T8	22,9	90,5		
T9	-	36,8		
T10	69,2	99,5		
T11	34,4	94,1	26.9	124
T12	47,5	-		
T13	-	70,2		
T14	-	41,2		
T15	38,5	-	14.5	104.5
T16	34,8	92,8	20.9	82.5
T17	24,8	88,2		
T18	8,8	76,1		
T19	29,1	91,8		
T20	6,4	74,2		
T21	27,0	-		

The analysis of the results shows that the liquid limit (w_l) is shifting towards the zone of w_l = 35 – 45 %, irrespective of the initial values. The high values of the liquid limit decrease drastically, those situated near the zone practically stagnate, and a slight increase was experienced at the low liquid limit values.
Similarly to the plastic limit (w_p) a tendency of shifting towards a certain zone can be experienced, similarly to the behavior of the liquid limit. This zone is situated at w_p = 25 – 35 %. The plastic limit is generally increasing, however in case of fat clays having high plasticity limit stagnation or decrease can be experienced.

The alteration of Atterberg-limits in the value of the plasticity index (Ip) also leads to shifting towards a zone (Figure 3). The value of plasticity index is shifting to the zone delimited by Ip = 5 – 15 %, corresponding to very fine sand and silt type soils, according to the description of the bound soils.

An investigation of the temporal aspects of the impact shows that the above tendencies appear during the first hour following mixing, however the most extreme alteration of the parameters could be measured appr. on day 7. The following period was characterized by stagnation, with slight shifts in case of certain soils toward the properties of an untreated soil.

4.2. *Alteration of the grain distribution*

The process of increased crumbliness and the more granular soil experienced at the plasticity index were tried to be delimited by an investigation of the grain size distribution. During the grain size distribution test and hydrometration of soil samples treated with lime, the soil particles settled very rapidly. The settling process took 5-15 minutes.

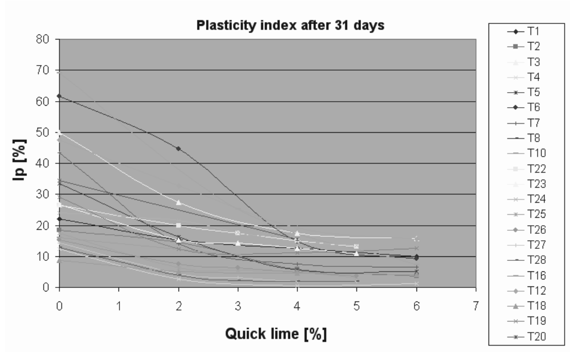

Figure 3. Alteration of the plasticity index plotted against lime dosage

This rapid sedimentation process produces the grain size distribution curve characterizing soils treated with lime. The section situated above hydrometration of the curve shows a picture identical with that of an untreated soil, plunging however at the section below 0.063 mm. The stabilized soils maintain this character later on, with the only difference that also the proportion of particles of above 0.063 mm becomes slightly higher. These alterations are visualized in Figure 4.
As was suspected this intensive coagulation that is not characteristic for the hydrometration of soils of natural stratification is triggered by the cation exchange taking place during lime stabilization. In order to prove it, the hydrometration was performed with a 15 months old sample, by means of admixing a significant quantity of dispersive material (sodium hexametaphosphate) to the mixture prepared in the measuring glass. During the test, a long lasting, continuous precipitation could be experienced as usual for natural soils. The obtained curve of grain size distribution is indicated in Figure 4 in purple color, showing a high conformity with the curve of an untreated soil.

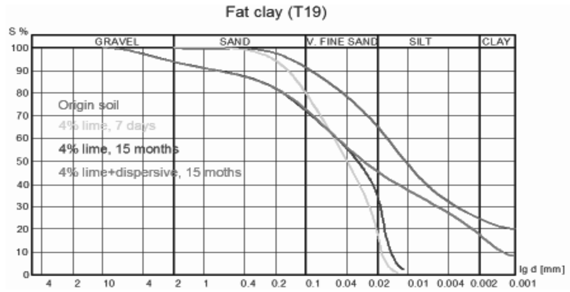

Figure 4. Alteration of the grain size distribution caused by a lime treatment of medium clay soil

It can be observed with the lapse of time that the more frequent presence of particles of above 0.063 mm of particle diameter can be explained with two other chemical processes of the lime stabilization: the cementation and carbonatization. The investigation of particles of above 0.063 mm by means of microscope and X-ray diffraction demonstrated the presence of aluminates and silicates leading to cementation, together with carbonatized limestone particles.

The results obtained from the investigation of plasticity and the grain size distribution show that the particles of a treated soil coagulate, cohere, resulting from the cation exchange. This coagulation creates a strong connection between the soil particles that cannot be dissolved by water, rendering it durable in the soil.
The coagulation is able to eliminate one of the biggest disadvantages of bound soils, i.e. the relatively high particle surface binding high quantities of water. The high level of water intake reduces namely the shearing strength and consequently the load bearing capacity of the soils.

5 ALTERATION OF THE LOAD BEARING CAPACITY OF THE SOIL

Drying and working in soils are facilitated by the addition of lime which is very important to constructers. Therewith the important to designers is an intensive increase of the load bearing capacity based on the effect of lime exerted on the soil structure. The load bearing capacity of soils is determined by their parameters related to shearing strength and deformation.

4.3. *Alteration of the parameters related to shearing strength*

In order to define the internal friction angle (Φ) and the cohesion (c), I have performed triaxial compression test over a long range of the above mentioned soils. Similarly to the previous procedures added lime was 2 %, 4 %, and 6 %, the temporal aspect has been investigated in ages of 1, 7, and 31 days.

The evaluation of the measurement results shows a growth of the values of friction angle and cohesion. At the 1 day old samples the growth showed a fully disordered picture, then the alteration of value „Φ" shift towards a single zone as the boundaries of consistency at the age of 31 days. In case of admixing an ideal quantity of lime, the soils are shifting towards the value of $\Phi=40^o$. A growth can also be measured at lower lime quantities, however its extent does not reach the value of 40^o that can be regarded as maximum, while the addition of an excessive lime quantity results in a stagnation or decrease. The curve fitted to the measurement results is visualized in Figure 5.

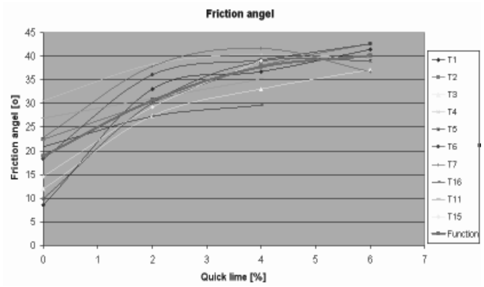

Figure 5. Increase of the friction angle at an age of 28 days, plotted against the quantity of lime

The equation of the fitted curve based on 10 different soil can be expressed with the following function:

$$\Phi = -0,589\,M^{2} \times 7,07\,M + 18,9 \qquad (1)$$

where

Φ - internal friction angle

M - added lime quantity

With the use of the function, the fitting to the points could be expressed with the value of R^2=0.77.

The function does not work at M=0% and it is limited to M=8%, which is the rationality quantity of added quick lime.

The extent of growth of the cohesion did not show a consistency similar to the previous one. The improvement amounted generally to several hundreds of per cent, with 150 % experienced in the worst case (Figure 6).

The above demonstrated alterations of the shearing parameters have been measured at an age of 28 days, when only the impact of the cation exchange prevailed to a significant extent among the chemical processes taking place during stabilization.

Further alterations triggered by the puzzolan reaction have been tested on a sample taken at an age of 15 months. According to the results of measurement, no changes could be experienced at the friction angle of the stabilization, it maintained its value of $\Phi=40^o$, however the value of the cohesion increased to c = 787 kPa, from the value of c = 343 kPa measured at an age of 28 days. The alteration of the shearing parameters clearly demonstrates the cementation effect of the puzzolan reaction.

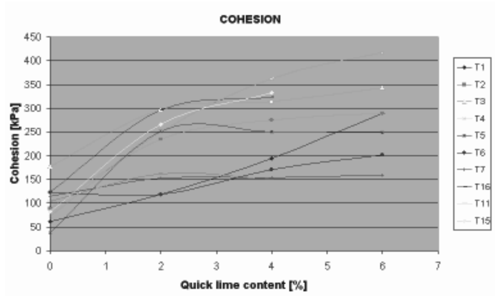

Figure 6. Increase of the cohesion at an age of 28 days, plotted against lime quantity

6 CONCLUSIONS

During a soil stabilization with lime, the Ca^{2+} ions introduced into the soil attach to the surface of the clay particles, replacing the cations located there previously. Due to the high charging of the Ca^{2+} ions, the clay particles coagulate. The coagulation exerts a decisive effect on the soil structure, resulting the plasticity index in a shifting towards a certain zone. This effect leads to the elimination of the silt and clay particles, resulting in an intensive reduction surface of the particle of the stabilizations.

Due to the coagulating particles, the friction angle increases, and also the value of cohesion becomes higher. The addition of lime results consequently in a growth of the compression strength of the soil, leading to an increased load bearing capacity.

Contrary to the literature, I regard to remark that the positive impacts of lime stabilization of the soil is basically a result of the cation exchange, while the puzzolan reaction playing only a secondary role.

It is also important to remark that the lime stabilization of soils is not only suitable for the drying up of soaked soils. With the application of a planned and properly executed stabilization, load bearing capacity of ballast materials can be achieved with local soils regarded or qualified as unsuitable. Accordingly, the ballast and pavement layers can be effectively reduced, and the quantity of delivered external materials minimized.

7 REFERENCES

Boromissza T. 1999. Hungarian design rules of concrete pavements. *Közlekedési és mélyépítési szemle (évfolyam, szám, oldalak) (in Hungarian)*

Bowles XXX: *Engineering Properties of Soils and their Measurement*

Filep Gy. 1988. *Chemistry of soils*. Akadémiai kiadó, Budapest

Jan M. A., Walker R. D. 1963. Effect of Lime, Moisture and Compaction on a Clay Soil. *Highway Research Record* 29, 1-12.

Kézdi Á. 1967. *Stabilized earthroads*. Akadémiai Kiadó, Budapest

Little D.N. 1999: *Evaluation of Structural Contribution of Lime Stabilized Soils and Aggregates, Summary of Findings*, 1999 National Lime Association

Lohmeyer G., Ebeling K. 2001. *Building of industrial floors*. Magyar Építőanyagipari Szövetség Építésügyi (in Hungarian)

Mitchell J.K., Hooper D.R. 1961. Influence of Time Between Mixing and Compaction on Properties of a Lime-Stabilized Expansive Clay, *Highway research Board* 304, 14-31.

Nemesdy E. 1983. *Building technology of road pavements*. Tankönyvkiadó, Budapest (in Hungarian)

Szendefy J. 2008. Impact of soilstabilization with lime to the structure and bearing capacity of internal soils, *Geotechnic conference, Ráckeve (in Hungarian)*

ÚT 2-1-222-2002, Útügyi Műszaki Előírás:General Rules of Geotechnical Design of Roads (in Hungarian)

Wang J. W. H. 1963. Comparative Studies on the Effects of Hydraulic, Calcitic and Dolomitic Limes and Cement in Soil Stabilization, *Highway Research Record* 29, 42-54.