Bearing capacity and durability of stabilized soils with HRB

Capacité de portance et durabilité des sols stabilisés avec HRB

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ABSTRACT: Part of the soils are unsuitable earthworks material, therefore big volume of soil replacements may be necessary in road and railway construction. Soiltreatment modify the properties of the soil to become suitable for earthworks. It increase the durability against changing of the moister content and reduce the risk of frost. The suggested binder is lime to cohesive soils and cement to granular soils. Hungary is mostly covered by transient soils, where lime and cement mixture binders are recommended. The paper presents the laboratory results and analyse of Vicalaco HRB based on 144 CBR and 72 uniaxial tests.

RÉSUMÉ: Le fait qu'une partie des sols n'est pas favorable á la realisation des ouvrages en terre, des importantes echanges de sol peuvent être necessaire dans le cadre des investissments d'infrastructure. Avec un traitement adéquat les sols en place peuvent être améliores dans la mesure exigēe de la qualitē en terre, en plus leur portance ainsi que leur résistance contre l'eau pourra etre améliorē et, en même temps, la sensibilitē au gel diminuēe. Le liant le plus efficace pour le traitement des sols cohérents est le chaux et le ciment pour les sols sableux et caillouteux. Une grande partie de la surface de la Hongrie est couverte des sols mixts ; pour le traitement de ces sols on pourrait d'utiliser un melange de chaux e ciment. Dans le cadre de nos recherches on a examiné au laboratoire des liants mixtes chaux plus ciment VIACALCO ; dans le cadre de ces analyses nous avons étudié 144 échantillons de CBR et 72 de UCS dans le but de pouvoir detérminer la portance et la durée des sols traités.

KEYWORDS: soil-stabilization, soil-treatment, HRB, CBR, durability, frost resistance

1 INTRODUCTION

The area of Hungary is mostly covered with soils, rock outcrops can only be found in some mountainous areas. Roughly two-thirds of the area covered with soils is comprised of weak cohesive, so-called transitional soils, while the remaining regions are made up of cohesive and poorly graded sandy soils. Transitional soils appear as fluvial sediments, aeolian loess and fluvio-eolian combination of these or deluvial soils as the result of erosional processes. Poorly graded sands are also deposited by wind, while cohesive soils rather have fluvial origin. Weak cohesive soils are composed of mainly silt and sand fractions; their clay content varies between 5-20%.

Due to the near-surface abundance of the aforementioned soils, they are often subjected to large volume earthworks, but their unfavourable properties make their scope of utilization limited. Bearing capacity of cohesive soils is sensitive to moisture content due to the presence of fines that are capable of absorbing relatively large amount of water. In poorly graded sands, because of the similar-sized particles, stable soil skeleton cannot develop, loading pushes sideways grains rolling on top of each other. Due to their non-adequate bearing capacity, the construction of a coarse-grained improvement layer is necessary on top of them. Moreover, soaking of transitional and cohesive soils can cause problems regarding their placement and bearing capacity, which can largely increase uncertainty in both construction time and budget.

Soil treatment can provide a technically and economically optimal solution for the above problems, with which the properties of soils can be improved effectively (Gáspár L. 1959, Kézdi Á 1967, Stocker P. 1972, Szendefy J. 2009). It is expected from a soil treatment method to improve soils' workability, hence making it possible for broader water content interval, increase their bearing capacity and turn them insensitive to water and frost effects. Thereby local soils can be utilized for broader purposes, and the amount of imported coarse-grained soils can be reduced (Biczók E. 1982, Kézdi Á 1967).

2 PRESENTATION OF TESTED SOILS

The primary purpose for the selection of testing materials was to purposefully study the effect of Viacalco binder on transitional soils, and their lower (cohesive soils) and upper boundaries (granular soils) to illustrate the performance limits of the binder. At the selection of soil samples, it was targeted to choose such materials, that besides their soil mechanical properties, differ from geographical and geological aspects as well.

In the present study 4 different soils were tested; their grain size distribution is shown in Figure 1.

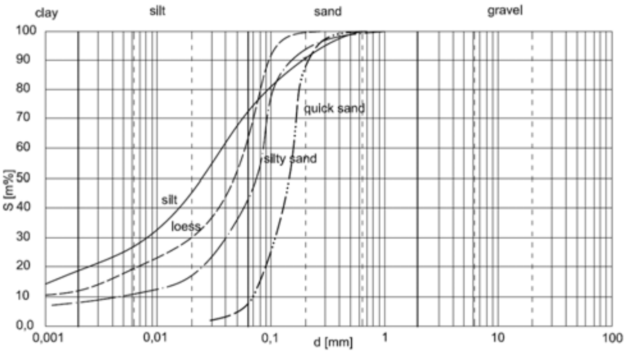

Figure 1. Grain size distribution of the tested soils

Poorly graded sands are typical aeolian sediments of Hungary, which is often called quicksand, because due to the winds it is still in motion in many places. The soil represents the upper boundary of transitional soils, or it can be already regarded as a granular soil. Its steep grain size distribution curve makes it less suitable for embankment construction, according to Út 2.1-222:2007 standard it is unsuitable for compaction.

Moving towards the fine-grained soils, the next sample was a silty sand from the town of Győr. This soil well-represents Holocene sediments near the main rivers of the country. Because of their near-surface presence, they are often used as subgrades for roads, railways, industrial floors and pavements.

Silty sands and sandy silts are favourable from compaction point of view, due to their abundance they are often used as materials for infrastructure investments (roads, railways, levees). Although, they can be well compacted, their bearing capacity is extremely sensitive to water (hydro-collapsible) as even at the optimal or higher water content their bearing capacity decreases rapidly.

The grain size distribution of the third soil sample was similar to that of the sample from Győr, but its geological history was totally different. The loess sample is a frequent near-surface soil of Hungary, which covers more than the 1/3 of its area. Similarly to the first sample, it has also aeolian origin, but its grain composition is more diverse. Besides its abundance, it is known for its special, macroporous structure.

While poorly graded sands can be regarded as the upper, then silts as the lower boundary of transitional soils. Further increasing the fines content brings us to clayey soils, which can be treated with quicklime (Little Dallas 1987, Szendefy 2013), therefore they were not included in our research. The fourth sample is a fluvio-eolian silt, so a wind-deposited sediment that was later reworked by water. The soil has similar properties as sandy silts and silty sands, namely it can be compacted well or moderately, but it can lose its bearing capacity due to moisture.

3 PRESENTATION OF BINDERS AND LABORATORY TESTS

The goal of the study was to evaluate the performance of Viacalco hydraulic road binder (HRB). The manufacturer of the product, who mainly produces lime, realized the opportunities hiding in soil treatment and has been doing researches in Hungary since the early 2000's (Szendefy 2009). The successful researches resulted in the spread of soil treatment in the country, and lime was used for the subsoil improvement of numerous highways and industrial facilities. Most part of the county is covered with transitional soils, which can be treated with lime, but because of their fines content hydraulic bonds poorly develop in them. To create hydraulic bonds, the presence of hydraulic binders or trass materials contributing to their formation are necessary, thus efficiency of lime was increased by admixing such materials. Within Viacalco product family, the specific products bear the name according to the mixture ratio of lime and added hydraulic materials, so Viacalco C30 contains 30% CaO and C50 has 50% active lime.

One of the goals was to compare the performance of C30 and C50 binders with other known binders, therefore tests were made with soils close to granular with cement binder and soils close to cohesive with lime binder. Every sample was tested with 3 different binder dosages: 28.5kg/m^3, 57kg/m^3 and 95 kg/m^3. The tested mixtures are presented in Table 1.

Table 1. Types of tested mixtures, binder dosage was 28.5kg/m^3, 57kg/m^3 and 95 kg/m^{3}for all cases

Type of binder/soil	*C30*	*C50*	*lime*	*cement*
sand	✓	-	-	✓
silty sand	✓	✓		✓
loess	✓	✓	✓	✓
silt	✓	✓	✓	-

Bearing capacity of soil samples treated with different binders were obtained by means of CBR tests. To evaluate influence of setting time and weather conditions on bearing conditions the following storage times and conditions were determined:

- 3 days in vapour tight packaging,
- 10 days in vapour tight packaging, then 4 days underwater storage,
- 4 days underwater storage,
- 28 days in vapour tight packaging.

The 4 soil types, with 3 dosages of 4 different binders and the evaluation of 4 different weather and environmental conditions resulted in altogether 144 CBR tests. Besides these, uniaxial compression tests were carried out on samples stored for 7 days at 40^{o}C in vapour tight packaging then subjected to 4 freeze-thaw cycles to assess the frost resistance of treated soils. Control measurements from untreated samples were considered as unnecessary since based on previous experiences, samples stored underwater for multiple days lose their bearing capacity, therefore tests performed on them cannot be evaluated.

4 EVALUATION OF TEST RESULTS

Two different laboratory tests were used for the measurement of treated soils' bearing capacity. By means of CBR testing, the bearing capacity that can be considered during design can be determined, while uniaxial compression tests were used to determined frost resistance.

4 .1 *Evaluation of CBR test results*

To help easier interpretation, CBR results in the graphs are shown with the commonly used E_2 [MPa] bearing capacity modulus.

Based on the results, cement treatment provides a quick and effective solution for the treatment of the sand, because even at the initial period after mixture (after 3 days curing), the majority of bearing capacity had already developed (Figure 2.). However, bearing capacity of samples treated with C30 approached that of cement-treated samples as curing time passed. Soil samples improved with both binders showed sufficient resistance against water, no bearing capacity reduction was measured.

According to literature and experiences, sands with same grain size distribution as used in the present research can be associated with E_2 value between 30-50MPa. Their bearing capacity are less sensitive to water, but without cohesion, the grains move sideways upon loading, which makes them unsuitable for vehicle usage. Samples treated with binders gave bearing capacity modulus values of E_2 = 100-200MPa, which means 3-5 times increase. Based on these values, treated sands can reach similar bearing capacity as well graded sandy gravel and crushed stones.

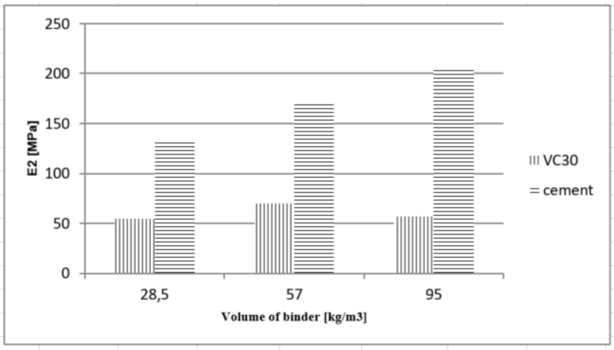

Figure 2. E2 bearing capacity of the treated sand soil after 3days curing

Typical surface soil formation of Hungary is silty sand, which can be properly compacted, but due to the presence of fines, its bearing capacity deteriorates quickly at or slightly above the optimal moisture content. Its bearing capacity around optimal moisture content is E_2 = 25-35MPa, while after increasing its moisture content it decreases to E_2 = 0-10MPa. Among the binders, the cement proved to be the quickest, which gave the highest bearing capacity after the initial curing days, but after some time the bearing capacity of HRB products exceeded than that of cement. Bearing capacity of samples stored for 10 days in vapour tight packaging then 4 days underwater didn't decrease, but contrarily even increased compared to its 3 days value and showed E_2 = 60-160MPa values (Figure 3.). Based on the results, to obtain adequate bearing capacity minimum 3% (~58kg/m^3) binder dosage is recommended to be selected during stabilization, with which bearing capacity typical for coarse-grained soils may be reached. But the most important aspect of utilizing binders is that the resistance of silty sands against water should be adequate.

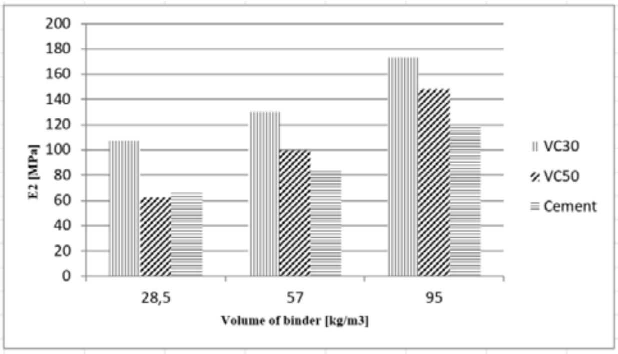

Figure 3. E_2 bearing capacity of the treated silty sand after soaking

Untreated loess soils have slightly more unfavourable strength properties than silty sands due to their higher fines content. However, stabilization during present study yielded higher bearing capacity values than it was measured for sand and silty sand. This higher bearing capacity can be explained by the flatter grain size distribution, thus extremely good grain structure of loess. The measurements showed that with proper binder selection and dosage E_2 value can even reach 250MPa or more, which is even a high value for crushed stone. Moreover, this bearing capacity can be considered as permanent, because after 4 days of underwater storage no reduction in it was noticed (Figure 4.).

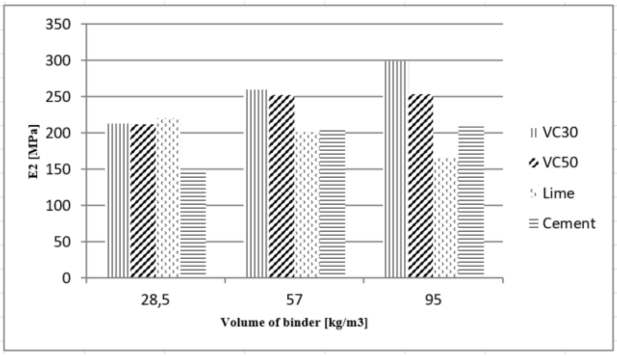

Figure 4. E2 bearing capacity of the treated loess after soaking

Using silt soils as earthwork material can impose significant hazards on the construction. Having soaked, its bearing capacity decreases to basically zero, hence not only the built embankment becomes unqualifiable, but transportation on it also becomes impossible. Loss of bearing capacity can be compensated with soil replacement, but besides considerable excess expenditure it can also upset the construction schedule causing the shifting of deadline. In rainy period, it also poses additional problems and risks that during soil replacement, the soil underlying the replaced layer can also get soaked, thus the replacement cannot fulfil its predestined function. Thus, the most important goal is to make the soil resistant against moisture. The C30, C50 and lime binders used for treating the silt could stabilize the soil extremely efficiently, securing high bearing capacity even in the initial days. The highest bearing capacity was given by the C50 binder containing 50% lime. The E_2=300-350MPa bearing capacity considerably exceeded than that of crushed stones.

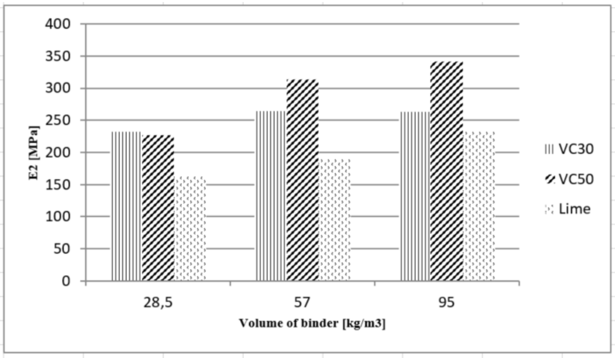

Figure 4. E2 bearing capacity of the treated silt after soaking

Based on the evaluation bearing capacity tests, it can be concluded that generally rapid cement used for soil stabilization gains the majority of its bearing capacity quickly, within a few days, while for quicklimes it typically takes approx. 7-14 days (Szendefy 2009, Mitchell and Hooper 1961). In addition, a tendency was apparent that moving towards more cohesive soils, binders with higher lime content provide efficient solutions for soil stabilization. In case of cohesive soils, binders with lime content can give permanently higher bearing capacity, and they are more favourable in reducing the soil's moisture content and improving its workability than cements.

4 .2 *Evaluation of UCS test results*

In accordance with the international literature (Mixture design 2006) freeze-thaw testing was carried out using uniaxial compression testing. Due to unsuccessful preparation and curing of small samples in previous laboratory tests, samples prepared in small Proctor mold were subjected to freeze-thaw cycles what proved to be successful regarding the subsequent tests. Evaluation of the tests were carried out following the criteria belonging to the highest expected freeze-thaw cycle (Table 2) as presented in the NLA report (Mixture design 2006), thus following the strictest requirements.

Table 2. Recommended UCS values of stabilization considered resistant against frost

Anticipated use	Recommended UCS [kPa]
Subbase, rigid pavement/floor slabs/foundations	≥ 850
Subbase, flexible pavement (>25cm)	≥ 900
Subbase, flexible pavement (20-25cm)	≥ 950
Subbase, flexible pavement (12-20cm)	≥ 1100
Base or bedding layers	≥ 1400

The test results show that in for the sand sample cement binder can result in much higher uniaxial compressive strength of the treated soil than C30. The results draw attention to the fact, that frost resistance is highly dependent on the amount of binder used, because for small dosage the UCS values given in

Table 2 were not reached. In case of cement binder, only the samples admixed with 95kg/m^3 binder proved to yield sufficient strength (Figure 5.).

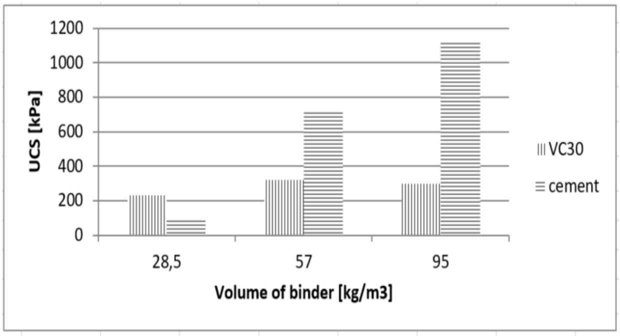

Figure 5. UCS of treated sand samples

Similar results were obtained for silty sand also, and the cement only gave sufficient strength for the loess with the highest dosage as well. On the other hand, lime-treated loess yielded adequate UCS values even with 57kg/m^3 dosage surpassing the highest requirement UCS>1400kPa (Figure 6.).

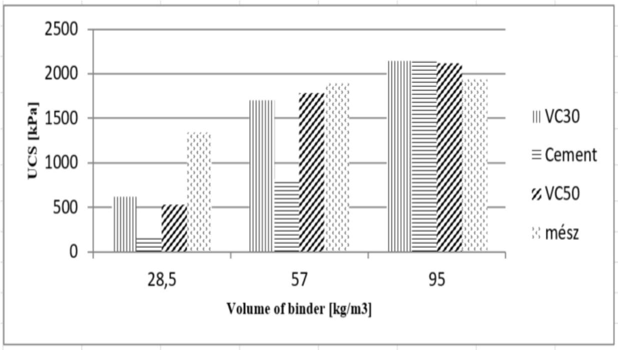

Figure 6. UCS of treated loess samples

Although, silt samples gave higher uniaxial compressive strength values than loess samples, the required UCS values can only be secured with 57 kg/m^3 and 95kg/m^3 dosages similarly (Figure 7.).

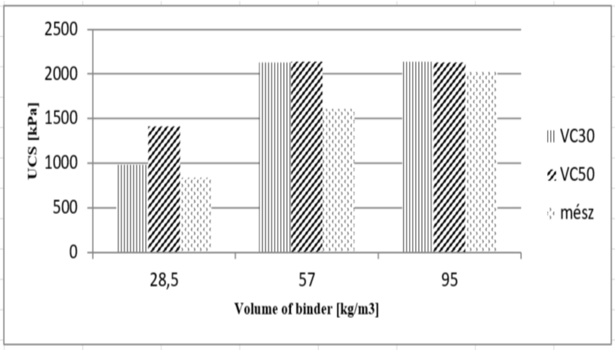

Figure 7. UCS of treated silt samples

5 CONCLUSIONS

Based on the large number of performed laboratory tests, it can be concluded that transitional soils can be treated with admixing them with binders. Soil treatment resulted in increased resistance against moisture, thus the volume of imported coarse-grained soils can be reduced during earthworks, and risks regarding the budget and time of constructions can be minimalized.

The CBR tests showed that treatment of soils with even 1.5% (28kg/m^3) binder dosage can yield bearing capacity similar to that of coarse-grained soils (sandy gravel, crushed stone), which remains permanent even if the soil gets soaked. However, frost resistance requires higher binder dosage (3-5%), thus different layers of the earthwork may require different binder dosages. While the material of an embankment not subjected to frost can be stabilized with smaller amount of binder, the upper portion of the embankment may require higher dosage.

Furthermore, the tests show that different types of binder may be necessary for different types of soil. Efficiency of binders can be verified by laboratory tests, but generally it can be stated that the more cohesive is the soil to be treated, the more lime-based binder is recommended to use.

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