MŰEGYETEM 1782

Budapesti University of Technology and Economics
Faculty of Civil Engineering
Vásárhelyi Pál Doctoral School of Civil Engineering and Earth Sciences

DISPERSIVE CLAYS IN FLOOD PROTECTION STRUCTURES

Gábor Nagy
civil engineer

Theses of PhD dissertation

Scientific supervisor:
Dr. László Nagy
associate professor

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1. INTRODUCTION

Soils are formed by physical, chemical and biological processes. The soil is composed of three different materials; the solid, the liquid and gaseous phases filling the pores between the soil grains. On one hand soil structure means the physico-chemical properties of the phases, on the other hand it means the way the individual particles are arranged and connected. The relationship between the phases is determined by the electrical properties of the surface of the particles, the pore fluid properties and its ionic composition, and the interactions between the phases.

The structure of cohesive soils can be often described as a *dispersive* system in which the size and the amount and distribution of the particles and the forces between the soil grains determine the properties and changes of the system. During contact between the soil grains there may be connections (cohesion, chemical bonds) which can lead to bearing capacity of the soils.

In cases where the system of connections between the particles cannot be properly formed, or by some external effect, the cohesive forces between the soil particles become weak or disappear, damages or failure mechanisms can occur (**Figure 1**). An example of damage to this connection system is the failure mechanism of dispersive soils. As a result of its name, it is like a dispersive medium, where the soil particles are dispersed in the pore fluid between them.

Fig. 1. Typical surface cracking on an embankment crest (Cibakháza, 2013), washed-out dispersive clay from an embankment (Tiszabura, 2012)

In addition to the type of soil with which properties we are dealing with, it is important to know the nature and composition of the pore fluid that is in contact with the soil, together with the current hydraulic conditions. The porous fluid between the particles is most often the water, so in the dissertation I use the term "pore water"

When evaluation water movement in soils, the starting point is Darcy’s Law (1856), according to which the rate of leakage between particles is proportional to the coefficient of permeability and the hydraulic gradient causing water movement and the seepage through the soil medium. Note that this relationship is true only for hydraulic gradients within a certain interval, but in the case of water movements in soils, Darcy's relationship can be used as a

good approximation. The factor "k" is the one that can be used as a soil parameter for the evaluation of water movement in both granular and cohesive soils.
The more granular soils have larger, while the cohesive soils can be characterized by a lower coefficient of permeability, so at the same potential difference and leakage pathway the water can move faster in the granular medium, while it is able to leak at a lower speed under the cohesive soil environment.

In my dissertation, I was dealing with the presence of dispersive soils in flood protection structures and the problems that could derive from it (Figure 2). Numerous domestic and international examples show that water-related structures, fillings, and dams have been damaged, which was clearly related to erosion of cohesive soils.

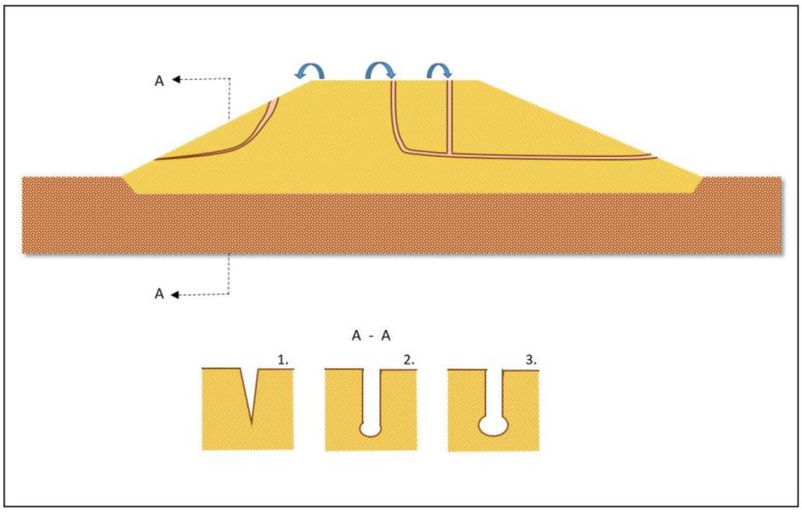

Figure 2. Development of tunnel erosion in embankments built from dispersive clays (based on Szepessy, 1981)

2. OBJECTIVES AND BUILD-UP OF THE DISSERTATION

2.1. Justification of the chosen topic and objectives

According to my observations, the most important part of the flood defense tasks in Hungary is to ensure the proper condition of flood protection structures. Failure mechanisms of these structures are various and can be linked to a number of factors. Different failure mechanisms and associated soil mechanical problems can be well matched, piping, slope stability issues, drying cracks are all well distinguishable phenomena and the associated geotechnical problems are important to monitor for proper interventions. The case of dispersive clays seems to be an exception, because its habit of degradation, the tunnel erosion can be discovered on the spot, but the type of soil itself, in which this erosion type can develop, is difficult to „define".

The aim of my research was to reveal the properties of dispersive clays and the properties of soil susceptible to erosion, according to my possibilities, so that such "unfavorable" soils can be better identified and detectable even when longer embankments and large amounts of soil samples needed to be evaluated.

I considered it important to examine the other possibilities besides geotechnical devices to detect dispersed soils. To this the starting point that a partly similar but partially different discipline also defines soils similarly (sodic) to the soils which in geotechnics considered as dispersive. One of my aims was to analyze the relationship between these two similar terms.

2.2. Structure of the dissertation

In the dissertation, I deal with the problems arising from the presence of dispersive clays in two parts. In the first part I deal with separate chapters:

- a possible explanation of the dispersion of soils, the construction of soil grains and the physico-chemical causes of the dispersive property;
- domestic and international research experiences on dispersive clays, with experience from previous researches.

The second part of the dissertation is described in the 3rd to 5th chapter. In the chapters I deal with:

- on-site and laboratory testing methods for the degree of dispersion of soils, by presenting my own measurement results for each method;
- the "remediation" of the problems arising from the presence of proven dispersive clays, the improvement and management of dispersive clays;
- the relationship between the concepts of "dispersive clay" in civil engineering and the "sodic soil" and the use of laboratory test methods related to the subject.

The research methodology was presented separately for each chapter. The dissertation Chapter 6 (as well as chapter 3 of the thesis booklet) summarize the elaborated theses. For the theses of the dissertation, I have provided the scientific publications where I published the results, these are collected separately from other literature references.

3. THESES

Thesis 1:

Monitoring of dispersive soils is an important task for the stability of flood protection structures. I have analyzed whether dispersive behavior can be linked to the cohesive soil type defined by MSZ EN 1997-1-2006. In the course of my investigations, I performed the pinhole test and the plasticity index definition on 62 samples of soil, and I analyzed the data series with the results of 234 soil samples found in archive expert opinions. I have evaluated the relationship between the degree of dispersion of soils with the Atterberg limits.

According to my results 93.7% (at least 91.8%) of the samples of the categories "dispersive" (**D1, D2**) and "intermediate" (**ND4, ND3**) or so-called erosion-susceptible were clays. On which I have found that the term "dispersive clay" used in foreign literature can also be used as a "diszperzív agyag" for Hungarian soils. Of the cohesive soil types, the examined samples were commonly found in medium and high plasticity clays (81.2%, at least 70.5%) (Figure 3).

I have elaborated a system for determining the relationship between soil dispersion degree and soil identification properties. Based on my laboratory results and archive data, I found that for Hungarian soils, dispersive behavior can be a characteristic of medium and high plasticity clays.

Figure 3. Distribution of 296 soil samples according to the plasticity index based on dispersion degrees

Publications related to the thesis: G. Nagy (2014a), G. Nagy and L. Nagy (2014), G. Nagy and L. Nagy (2015c), G. Nagy ± L. Nagy ± . R S H . F (2016)

Thesis 2:

The Gall- type void ratio (e_k) shows the sensitivity of cohesive soils to water. The procedure identifies four categories of sensitivity to water.

Evaluation:	Galli-type void ratio (e_k):
Aggregating	$0 < e_k < 2$
Watertight	$2 < e_k < 3,5$
Loosening	$3,5 < e_k < 6,0$
Diffluent	$6,0 < e_k$, or V cannot be measured

Table 1. Galli-type void ratio (1987)

I analyzed the correlation of the Galli-type void ratio with the degree of dispersion of the soils, which resulted in the determination of 125 pinhole tests and the Galli-type void ratio determination in soil samples. Based on my laboratory experimental results, the value of the Galli-type void ratio (e_k) was more than **3,50** in **90%** for the dispersive categories (**D1, D2**) and **83%** for intermediate (**ND4, ND3**) (**Figure 3.**).

Based on my results, I determined that dispersive behavior needed to be studied in the case of cohesive soils where the Galli-type void ratio is at least 3.50, i.e., the soil is categorized as "loosening" or "diffluent".

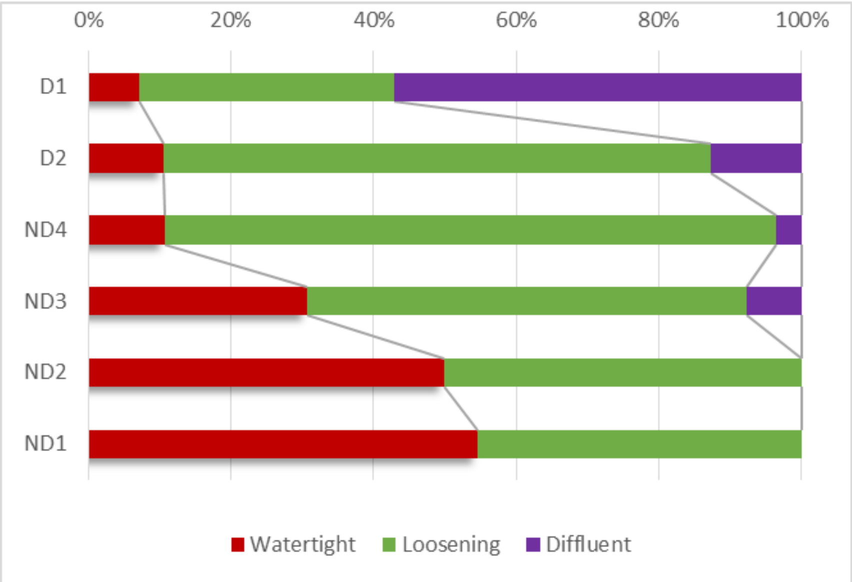

Figure 4. Relationship between the Galli-type void ratio and the degree of dispersion

Publications related to the thesis: G. Nagy and L. Nagy (2015a), G. Nagy and L. Nagy (2015b), L. Nagy – G. Nagy – Zs. Illés (2014)

Thesis 3:

Dispersive clays cannot be clearly distinguished from the erosion-resistant soils. In the case of embankment and flood protection structures, laboratory testing of a large number of samples are required.

Based on the results of my research, I have included a set of methods for the identification of dispersive soils, based on which I proposed a test program for the detection of dispersive soils, whose elements are as follows (Figure 5):

1. **Field monitoring, monitoring of surface phenomena.**
2. **Geoelectric profiles.**
3. **Determination of plasticity index.**
4. **Determination of Galli-type void ratio.**
5. **Performing the pinhole test.**
6. **In the case of dispersive clays, determination of the composition of the soil by phase analysis (XRD, DTA) or soil chemistry test (pH, pNa measurements).**

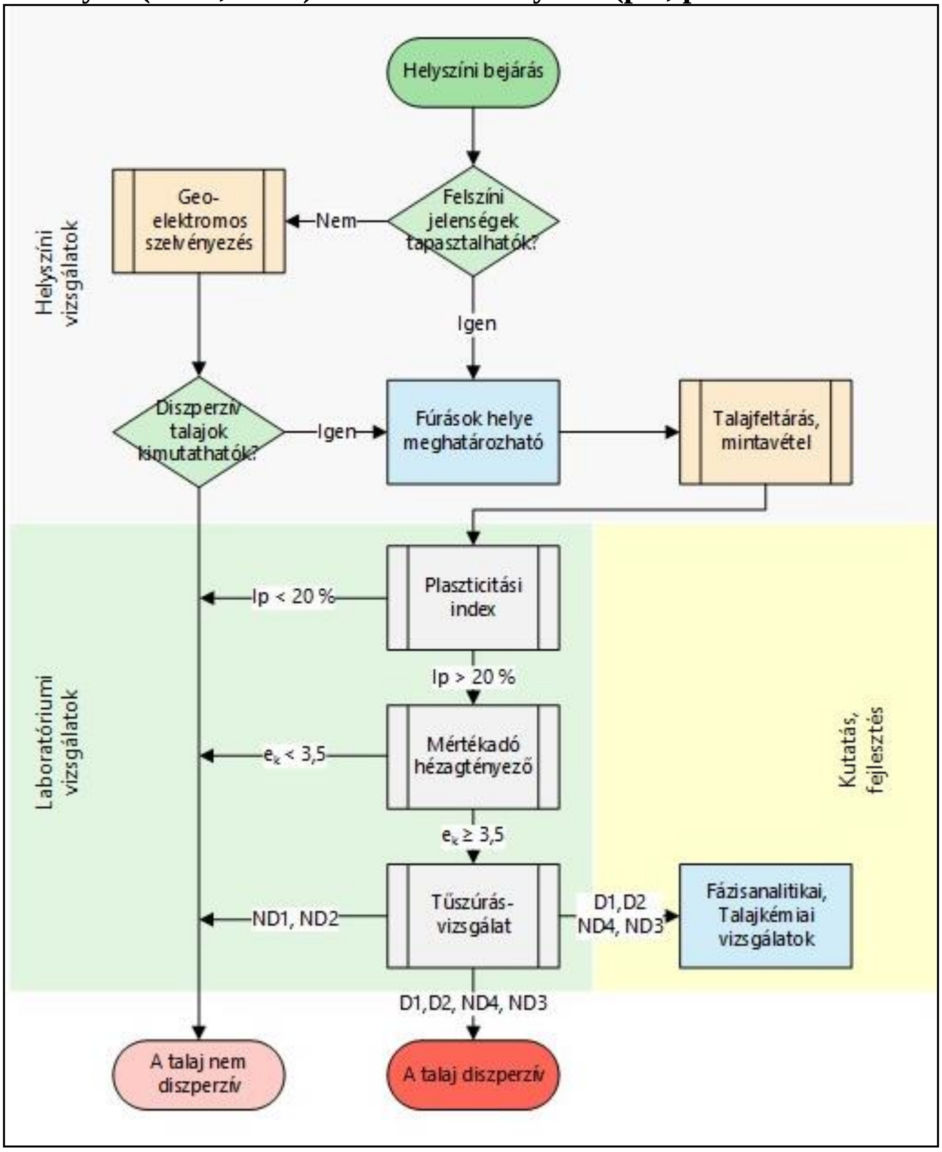

Figure 5. Recommended test program for dispersive clay detection

Publications related to the thesis: Zs. Illés – G. Nagy – L. Nagy (2015), G. Nagy (2014a), G. Nagy and K. Kopecskó (2016), G. Nagy and L. Nagy (2016b), G. Nagy – L. Nagy – K. Kopecskó (2016), L. Nagy – G. Nagy – Zs. Illés (2014)

Thesis 4:

Soil treatment with lime is not an unknown process in Hungary to improve the strength properties of soils, but there are no domestic experimental results for the improvement of dispersive clays. During my measurements, I tested the lime treatment of proven dispersive (**D1, D2**) soil sample groups from 4 locations in Hungary, examining whether the degree of dispersion of the various cohesive soils (degree of dispersion according to pinhole test) can be influenced by calcareous soil treatment (**Figure 6 and 7**). In the course of my investigations, the effect of soil treatment was verified by both pinhole testing and Galli-type void ratio determination.

Thesis 4.1:

Based on my results, I determined that the Gally-type void ratio (e_k) the degree of dispersion of soils (degree of dispersion according to pinhole test) and plasticity index of soils (I_P) decreases.

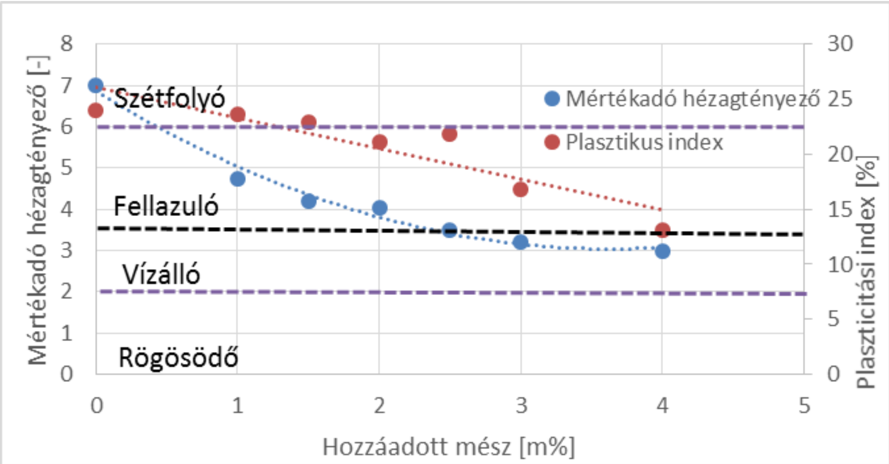

Figure 6. Effect of soil treatment with hydrated lime

Thesis 4.2:

Under laboratory conditions I have shown that in order to reduce the dispersive properties of the soils I studied, for the "non-dispersive"(ND2, ND1) category 2.0-4.0%, for the intermediate (ND4, ND3) category 1.0 to 2.0% added hydrated lime to the dry mass of the soil sample is sufficient.

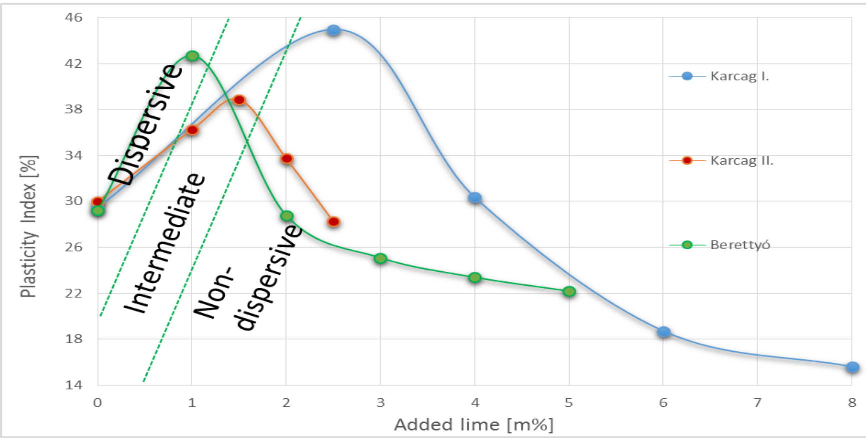

Figure 7. Changes of the Atterberg limits of the samples due to the lime treatment

Publications related to the thesis: Zs. Illés – G. Nagy – L. Nagy (2015), G. Nagy and L. Nagy (2015c), G. Nagy and L. Nagy (2016c), G. Nagy – L. Nagy – K. Kopecskó (2016), L. Nagy – G. Nagy – Zs. Illés (2014)

Thesis 5:

I have examined whether the dispersive property can be changed without adding binder, merely by mixing dispersive clays with non-dispersive. When testing a fill material, the soil can be treated before the construction with the appropriate proportion of soil mixture. Measurements were made with respect to the change in the dispersion degree of soil mixtures from dispersive (**D1**) and non-dispersive (**ND1**) samples. The degree of dispersion of the two soil groups was determined by pinhole tests.

Under laboratory conditions, I have shown that mixtures containing **30%** or more dispersive clays based on the dry weight of the samples were "intermediate" (**ND4, ND3**), mixtures with **40%** or more dispersive clay were "dispersive" (**D1, D2**) (**Figure 8**).

Based on my laboratory tests, I have found that in the case of the fill materials for the soils examined, soil mixing can be an effective means of eliminating dispersive behavior if less than 30% of dispersive soil is present on the dry weight of the mixture. In the case of an existing embankment, this means a considerable amount of soil removal, therefore I recommend soil mixing only to improve the properties of dispersive fill material.

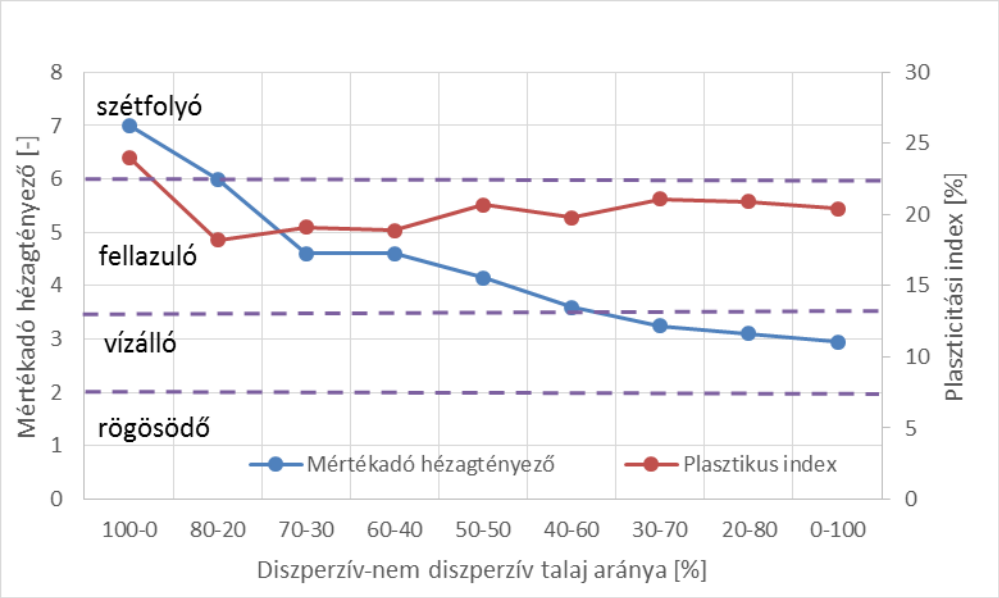

Figure 8. Effect of soil mixing on the properties of dispersive clays

Publications related to the thesis: G. Nagy (2017a), G. Nagy (2017b)

Thesis 6:

In literature, the behavior of dispersive and s soils is described almost identically in many cases. I analyzed the properties of dispersive and saline soils using both the tools and the approach of both geotechnics and soil sciences to explore the relationship between the two concepts. Under laboratory conditions, I used the geotechnical methods for sodic soils as well as soil science methods on dispersive clays.

Thesis 6.1:

In laboratory conditions, I showed that on average pH of the analyzed dispersive (D1, D2) clays had pH 9.0 and average pNa = 2.49 mol / l sodium ion concentration, while in the case of intermediate soils (ND4, ND3) = 8.4 and pNa = 2.67 mol / l. Based on my results I have found that the dispersed clays in Hungary are characterized by higher sodium and volume pH than the intermediate soils and, according to their values, they also correspond to the classification as sodic soils.

Thesis 6.2:

I examined whether the verified sodic soils can be classified as dispersive soils based on geotechnical definitions. Under laboratory conditions, I determined that the proven sodic are considered dispersive on the basis of the Galli-type void ratio ($e_k = V_{many}$) and dispersion degree (D1).

Thesis 6.3:

On the basis of the literature descriptions of dispersive and sodic soils and of Thesis 6.1, 6.2, I have found that under Hungarian conditions there are overlaps between the concepts of dispersive and sodic soils. Not all dispersive soil is sodic and not all sodic soil dispersive, but the two concepts have a "strong" overlapping (Figure 9).

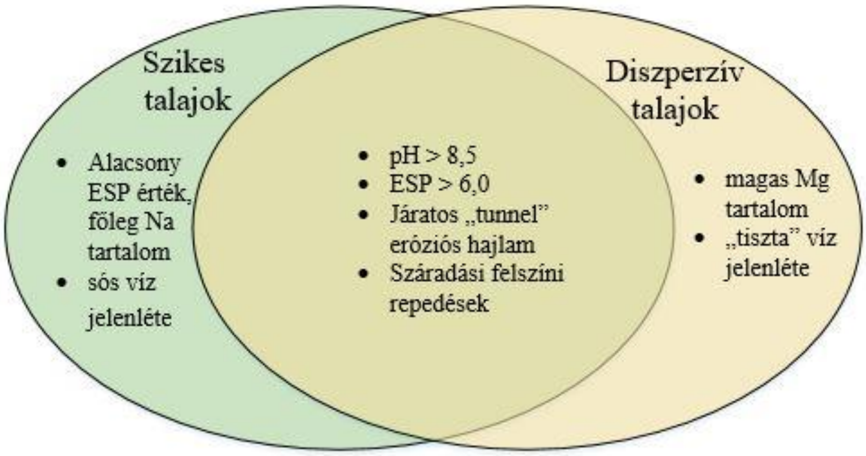

Figure 9. Overlapping between the soil scientific „sodic soil" and the geotechnical „dispersive clay"

Publications related to the thesis: G. Nagy and K. Kopecskó (2016), G. Nagy and L. Nagy (2016a), G. Nagy – L. Nagy – K. Kopecskó (2016)

4. USE OF RESULTS AND ADDITIONAL RESEARCH OPPORTUNITIES

Problems with dispersed clays have been recognized in the 1930s and have been linked to the "unfavorable" nature of soils since the 1960s. Nevertheless, in many cases dispersive clay-related damages and surface phenomena may occur during on-site visit of flood protection strucutres.

Based on my measurement results, I determined which on-site and laboratory test methods could be used to detect the dispersive properties can be treated.

My aim was to use the test program for the proposed dispersive clays and my research results on soil management to help with dispersion-related studies.

During various laboratory tests, several additional lines of research have emerged, which may lead to the clarification of the properties of dispersive soils. It is important to emphasize the more accurate assessment of the applicability of both on-site and laboratory geoelectric measurements for dispersive soils. In my opinion, making the on-site geoelectric profile is suitable for the identification of dispersive soils on the spot, and the laboratory measurement of the geoelectric parameters shown in the thesis is a promising procedure, in which case the test conditions of the method should be accurately determined.

It is worth mentioning the relatively simpler methods of analysis such as double hydrometer test, which is a modified version of a routine soil mechanics test, so it can provide useful information from a practical point of view.

It would be desirable to carry out reliability tests for each method of detecting dispersive behavior and to further explore the relationship between dispersive and sodic soils.

In addition, the relationship between the volume change of the soils and the degree of dispersion, as the two properties can be traced back to similar physicochemical properties, could be further explored as a further explorative direction, so exploring all these features could provide valuable information on dispersive soil knowledge.

5. List of Publications

5.1 Publications related to the thesis points of the dissertation

Foreign language journals published abroad

G. Nagy, L. Nagy (2016a): Comparison of the physical and chemical properties of the dispersive soils, In: Riscuri Si Catastrofe 16:(1) pp. 71-82.

A lecture in a foreign language published in an international conference

G. Nagy G., L. Nagy (2015c): Identification and Treatment of Erodible Clays in Dikes, In: Geotechnical Safety and Risk V., pp. 530-534. ISBN: 978-1-61499-1. Place: Rotterdam, Netherlands.

G. Nagy, (2017b): Effect of soil treatment and mixing on the dispersive behavior of soils, In: Proceendings of the 6th International Young Geotechnical Engineers' Conference (iYGEC6), Location: Seoul, Korea.(accepted)

A foreign language journal article published in Hungary

G. Nagy, L. Nagy, K. Kopecskó K. (2016): Examination of the physico-chemical composition of dispersive soils, In: Periodica Polytechnica-Civil Engineering, Vol. 60., Issue 2. pp. 269-279.

Hungarian-language journals published in Hungary

G. Nagy, L. Nagy (2016b): Geofizikai módszerek alkalmazása árvízvédelmi gátakban - diszperzív talajok kimutatása, In: Műszaki Ellenőr, V:(2) pp. 40-42.

G. Nagy, L. Nagy (2017a): Talajkeverés hatásának vizsgálata a talajok diszperzív viselkedésére, In: Tervezők Lapja, II:(1). pp. 11-13.

Hungarian-language published in conference proceedings

Zs. Illés, G. Nagy, L. Nagy. (2015): Erózió érzékeny talajok elektromos ellenállásának változása, In: G. Köllő (ed.) XIX. Nemzetközi Építéstudományi Konferencia, ÉPKO 2015, pp. 75-78, ISBN 1843-2123. Location: Csíksomlyó, Romania.

G. Nagy (2014a): Diszperzív talajok azonosítása árvízvédelmi gátak felszínén megfigyelt károsodások alapján, In: G. Köllő (ed.) XVIII. Nemzetközi Építéstudományi Konferencia: ÉPKO 2014, pp. 219-223, ISBN 1843-2123. Location: Csíksomlyó, Romania.

G. Nagy, K. Kopecskó (2016): Diszperzív talajok viselkedése az összetételük alapján. In: G. Köllő (ed.) XX. Nemzetközi Építéstudományi Konferencia: ÉPKO 2016, pp. 186-189, ISBN 1843-2123. Location: Csíksomlyó, Romania.

G. Nagy, L. Nagy (2014): Diszperzív talajok vizsgálata árvízvédelmi gátakban, In: Geotechnika 2014 Konferencia, Paper 13. 11 p., ISBN:978-615-80006-2-8.

G. Nagy, L. Nagy (2015a): Diszperzitásvizsgálat a gyakorlatban, In: G. Köllő (ed.). XIX. Nemzetközi Építéstudományi Konferencia: ÉPKO 2015, pp. 164-167. ISBN 1843-2123, Location: Csíksomlyó, Romania.

G. Nagy, L. Nagy (2015b): A Galli-féle mértékadó hézagtényező használata kötött talajok jellemzésére, In: Mérnökgeológia-Kőzetmechanika 2015, pp. 355-362. ISBN:978-615-5086-09-0, Location: Budapest, Hungary.

L. Nagy, G. Nagy, Zs. Illés (2014): Azonosítás és kezelés - diszperzív talajok az elméletben és a gyakorlatban, In: J. Szendefy, M. Vámos (eds.) 4. Kézdi Árpád Emlékkonferencia. pp. 156-168, ISBN:978-963-313-180-0. Location: Budapest, Hungary.

Hungarian-language, conference proceedings on CD

G. Nagy, L. Nagy (2016c): Meszes kezelés hatása a diszperzív talajokra, In: L. Szlávik (ed.) Magyar hidrológiai Társaság XXXVI. Országos Vándorgyűlés, pp. 1-9. Location: Debrecen, Hungary.

5.2. Other publications

A lecture in foreign language, published in an international conference

G. Nagy, (2014b): Examination of thixotropy in geotechnics: red mud and bentonite, In: Pollack Periodica: An International Journal for Engineering and Information Sciences 9 (2) pp. 131-139.

G. Nagy, L. Nagy (2013b): Examination of the red mud's thixotropic behavior, In: J. Józsa, R. Németh, T. Lovas (eds.), Proceedings of the Second Conference of Junior Researchers in Civil Engineering, pp 129-135. Location: Budapest, Hungary.

Hungarian-language journals published in Hungary

G. Nagy, I. Kádár, Z. Bán (2015a): Malajzia "okos" alagútja: a SMART, In: Műszaki Ellenőr IV:(11) pp. 43-46.

G. Nagy, I. Kádár, Z. Bán (2015b): Malajzia multifuncionális alagútja a SMART, In: Mérnök Újság XXII.:(12) p.28. 4p.

G. Nagy, L. Nagy (2013a): A bentonit tixotróp viselkedésének vizsgálata, In: Műszaki Ellenőr II. évf. 2013. november pp. 41-43.

L. Nagy, G. Nagy (2013): Buzgárból kimosott talaj entrópia-vizsgálata, In: Hidrológiai Közlöny 93: (3) pp. 29-33.

Hungarian-language published in conference proceedings

G. Nagy, L. Nagy (2015d): Árvízvédelmi töltésből kimosott talaj szemeloszlási entrópia vizsgálata, In: Mérnökgeológia-Kőzetmechanika 2015, pp. 363-370, ISBN:978-615-5086-09-0. Location: Budapest, Hungary.

R. Nagy, G. Nagy (2015): Agyagtalaj stabilizációja pernyével, In: Mérnökgeológia-Kőzetmechanika 2015, pp. 347-354, ISBN:978-615-5086-09-0. Location: Budapest, Hungary.

T. Huszák, G. Nagy, L. Nagy (2013): Reológiai jellemzők vizsgálata a geotechnikában, In: Mérnökgeológia-Kőzetmechanika 2013, pp. 71-76, ISBN:978-615-5086-06-09. Location: Budapest, Hungary.

G. Nagy, T. Huszák, L. Nagy, K. Kopecskó (2013): Vörösiszap tixotróp viselkedésének vizsgálata, In: 3. Kézdi Árpád Emlékkonferencia. 274 p, ISBN: 978-963-31308-1-0. Location: Budapest, Hungary.

G. Nagy, T. Huszák, K. Kopecskó, L. Nagy (2013): Tixotróp viselkedés a geotechnikában – a bentonit, In: Z. Tompai, A. Mahler, A. Takács, G. Varga (eds.) Geotechnika 2013 Konferencia, 60 p. ISBN: 978-963-89016-7-5. Location: Ráckeve, Hungary.

Hungarian-language, conference proceedings on CD

L. Nagy, G. Nagy (2012): Buzgárból kimosott talaj jellemzése a szemeloszlási entrópia segítségével, In: L. Szlávik, Z. Kling, E. Szigeti (eds.). Magyar Hidrológiai Társaság, XXX. Országos Vándorgyűlés, pp. 1-9. ISBN: 978-963-8172-29-7. Location: Kaposvár, Hungary.

Other

G. Nagy (2011): Buzgárosodás a szemeloszlási entrópia alapján (absztrakt), In: XXX. OTDK Műszaki Tudományi Szekció Kiadványa, pp. 259, ISBN: 978-963-720-85-5. Location Baja, Hungary.

G. Nagy (2010): Buzgárosodás a szemeloszlási entrópia alapján, In: Építőmérnöki Kari TDK, Geotechnika és geológia szekció, pp 1-72. Location: Budapest, Hungary.