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Dispersive clays – approach, assessment, connections

Argiles dispersif – approche, évaluation, liens

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ABSTRACT: Dispersive soil is a common term when evaluating the soils applicability for fill materials during embankment construction. The unfavorable property of the soil, that seperates them from the „regular“ clays which are usually applied in flood protection structures is the capability to erode due to the presence of relateively pure water inside the soil structure. The paper is about the approach, exploring the engineering perspectives when the presence of soil dispersibility needs to be handled. Also, the paper is about the assessment, by collecting the available methods of classification. Due to this characteristic of dispersive clays several identification methods were invented to be able to distinguish the different types of cohesive soils. In this paper the main identification methods and their applicability is summarized and evaluated based on laboratory test results, and a decision tree structure of the needed tests are presented. At last, but not least, the paper is about connections. This chapter is covering the similar soil parameters that are mentioned in different fields of study, but barely compared when the essence of soil dispersibility needs to be grabbed.

RÉSUMÉ: Le terme sol dispersif est un terme courant pour évaluer l’applicabilité des sols aux matériaux de remblayage lors de la construction de remblais. La propriété défavorable du sol, qui le sépare des argiles „ordinaires“ qui sont habituellement utilisées dans les structures de protection contre les inondations, est la capacité de s’éroder du fait de la présence d’une eau relativement pure dans la structure du sol. Le document traite de l'approche, explorant les perspectives d'ingénierie lorsque la présence de dispersibilité du sol doit être traitée. En outre, le document traite de l'évaluation en rassemblant les méthodes de classification disponibles. En raison de cette caractéristique des argiles dispersives, plusieurs méthodes d’identification ont été inventées afin de pouvoir distinguer les différents types de sols cohérents. Dans cet article, les principales méthodes d’identification et leur applicabilité sont résumées et évaluées sur la base des résultats d’essais en laboratoire, et une arborescence décisionnelle des essais nécessaires est présentée. Enfin, le document traite des connexions. Ce chapitre couvre les paramètres de sol similaires mentionnés dans différents domaines d’étude, mais à peine comparés lorsque l’essence même de la dispersibilité du sol doit être saisie.

Keywords: Dispersive soil, identification, soil treatment, sodic soil, void ratio

1 INRODUCTION

Soils are formed by physical, chemical and biological processes. The soil is the composition of three different phases; most importantly the solids, and the liquid and gaseous phases filling the pores between the soil grains.

Generally, the 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 (Carey 2014). 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 (Fig. 1).

An example of damage to this connection system is the failure mechanism of dispersive soils (ICOLD 1990). As a result of its name, it is like a dispersive medium, where the soil particles are dispersed in the pore fluid between them.

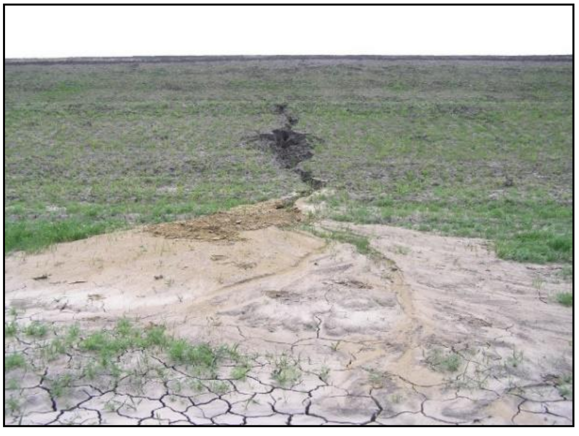

Figure 1. Washed out material from an embankment containing dispersive soils

2 APPROACH

To be able to handle the problem and evaluate properly the soils that are suspected to have dispersive properties, it is important to understand the parameters and behavior in question.

When collecting information about previous cases of soil dispersibility, the main symptoms are similar (Sherard et al. 1972):

1. without any detailed investigation, fill materials were selected for construction of flood protection structures.
2. In many cases the construction was not technologically sound, which lead to shortage on compaction.
3. The first fill of reservoirs, and the first greater flood caused severe damages to the structured mentioned.
4. The mechanisms rising from the presence of water lead to erosion-type failures.
5. Detailed investigation of the soils usually leads to the identification of dispersive properties, high amount of clay minerals, but various soil conditions.

The last part of the listing is the main difficulty when summarizing the parameters of soil dispersibility, namely because the geological origin cannot be precisely stated (DPIW 2009).

In the case of dispersive soils, the geological life-cycle and the interactions with different materials that are defining the behavior of dispersive soils.

As an example, the article of Vendl (1951) can be mentioned. He stated that for Hungarian soil conditions, the valley of river Tisza should be investigated because the dispersive soils can evolve at locations where the subsoil and groundwater conditions are poor in lime. Based on this hypothesis Vendl (1951) excluded the Danube embankment from the investigation.

During our research several Hungarian sites were visited, and samples taken. Fig. 2. plots the sites were dispersive clays were found, and it shows a great correlation with Vendl’s theory.

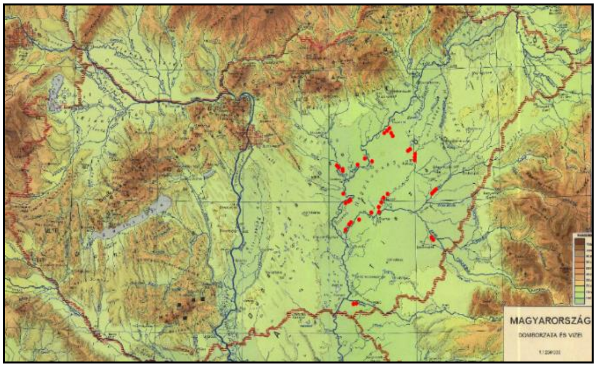

Figure 2. The locations where dispersive clays were found during the research marked with a red dot

The key point of the dispersive behavior can be defined differently. Based on Mitchell (1974) the effect of the dispersion, the structural breakdown is due to the resultant of the repulsive and attractive forces acting. (Fig. 3.)

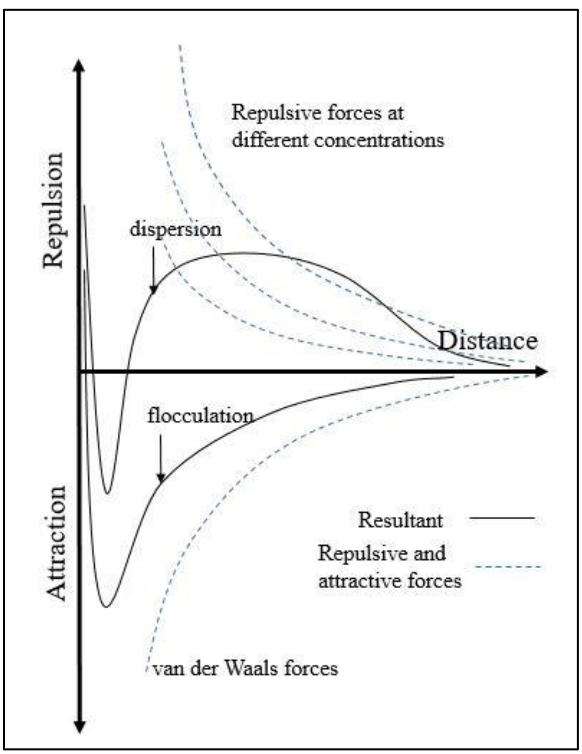

Figure 3. Repulsive and attractive forces acting on the surface of soil colloids (based on Mitchell)

It suggests that the dispersive behavior is depending on the distance from the clay surface and the ionic concentration of the pore water. Mitchell's assumption leads to the examination of the double layer theories that are known for soils.

Based on Filep (1988) the Helmholtz, Gouy-Chapman and Stern double layers that were explored to define the distribution of the ions in the diffuse double layer around the surface of the hydrated soil colloids.

Szabó (1999) suggests that the double layer is following an exponential decreasing by the function of Eq. (1):

$$\Psi_x = \Psi_0 \cdot \exp(-\kappa \cdot x) \qquad (1)$$

where Ψ_x is the potential at the distance of x from the surface, Ψ_0 is the electric potential at the surface of the colloid particle, κ is the constant depending on "density" of the double layer.

In Eq. (1) κ defines the parameters affecting the thickness of the double layer explained in Eq. (2):

$$\kappa = sqrt((\pi \cdot \eta_0 \cdot \epsilon^2 \cdot v^2)/(D \cdot k \cdot T)) \quad (2)$$

where η_0 electrolyte concentration (mol/cm^3), ε is the unit electronic charge (coulomb), v is the cation valence (-), D is the dielectric constant of the medium (-), k is the Boltzmann constant (J/K), T is the temperature (K).

2.1 *Risk factor*

The main risk is originated from the fact that dispersive soils cannot be distinguished by visual classification, and the Atterberg limits or grain size distribution are also inadequate to determine whether the soil is dispersive or not.

The finite element models or the calculation methods used are not able to handle the parameters which are describing the dispersive soils, therefore their evaluation had to be made separately.

Earlier experiences (Nagy, Nagy 2016) showed that for Hungarian soils the dispersive behavior is most likely for medium or high plasticity clays, but the correlation between the Atterberg limits and the dispersive category of soils suggests the need for further and detailed investigation.

According to the Eurocode 7 Table 1. collects the tests that are available for dispersive soil identification.

Table 1. Laboratory tests to evaluate dispersive behaviour based on Eurocode 7

Test	Approach
Pinhole test	The effect of different hydraulic gradients on the erosion
Double hydrometer test	Difference between the grading curves performed with and without a dispersing agent
Crumb test	Instability of the soil structure during interaction with relatively pure water
Dissolved salt content	Effect of clay minerals on the structural breakdown

According to Table 1 four methods are available for identification of the dispersive behavior. Literature and earlier experiences however in most cases suggesting, that the pinhole test is the most reliable, while the Crumb test can be a good tool to give a quick evaluation on the field as a quick and simple test.

During our research several testing methods were used whether they are applicable for the purpose.

2.2 Galli-type void ratio

One of the test should be highlighted is the determination of the Galli-type void ratio. The Gall type void ratio (e_k) shows the sensitivity of cohesive soils to water. The test is based on the sedimentation of soils in a test tube under 48 hours. At the end the measured volume of the soil sediment is the basis of the calculation by Eq. (3).

$$e_k = \rho_s \cdot \frac{V}{m_d} - 1 \qquad (3)$$

where ρ_s is the bulk density of the soil (g/cm^3), V is the volume of the sample (cm^3) and m_d is the measured dry mass of the soil sample (g).

After the 48 hours sedimentation if the soil contains large amount of fine grains, some fine particles are not able to settle due to the resultant of the forces acting. For small particles the resultant of the uplift of the water and the self-weight can lead to a state where the particle is at a floating state and cannot settle in time.

Based on the Galli (Nagy, Nagy 2015) the method distinguishes the soils by their swelling characteristics and classifies the samples into four categories shown in Table 2.

Table 2. Galli-type void ratio evaluation

Evaluation	Galli-type void ratio (e_k)
Aggregating	$0.0 < e_k \leq 2.0$
Watertight	$2.0 < e_k \leq 3.5$
Loosening	$3.5 < e_k \leq 6$
Diffluent	$6 < e_k$ or "V" cannot be measured

The outcome of the test distinguishes the two main result, in one case an exact volume can be measured, and the Galli-type void ratio can be calculated.

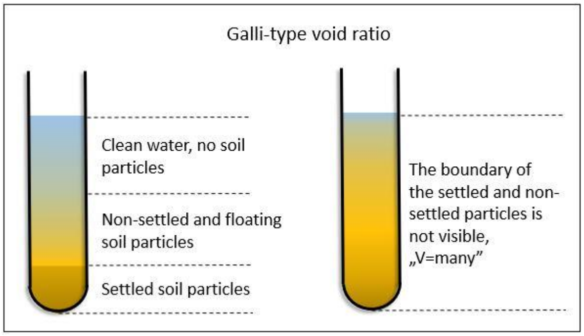

Figure 4. Outcomes of the Galli-type void ratio

While in the other case there is no significant border of the settled soil particles and the water on top of them, but there is a turbid mixture of solids and water (see Fig. 4.).

During our research 125 soil samples were examined there the Galli-type void ratio and the dispersive category based on the pinhole test were identified (Nagy, Nagy 2015).

Based on laboratory test results, the value of the Galli-type void ratio was greater than 3.5 for 90% of the samples that were classified as dispersive (D1 and D2), and 83% of the samples which were in the intermediate category (ND4 and ND3).

This correlation leads to a statement that the Galli-type void ratio is applicable for identification of dispersive soil behavior.

Also, if a soil is characterized by an e_k value greater than 3.5 than that sample should be tested by the pinhole device to determine the capability of dispersive behavior.

2.3 *Testing methods*

During the research several testing methods were applied to evaluate the dispersive behavior, a few of the most promising are collected in Table 3.

Table 3. Methods applied for dispersive behaviour categorization

Method	Test	Approach
Geophysical	In situ	In situ resistance of the soil layers
	Laboratory	Behavior of a compacted soil sample under laboratory conditions
Phase analytical	XRD	Mineral composition
	DTA	Weight losses of the minerals by ignition

According to detailed laboratory work a testing program was constructed, which helps the evaluation of the soil dispersibility stepwise, by starting with the application of simpler methods and at each stage exclude the soils that are not susceptible for dispersive behavior.

The flow diagram of the testing program is shown at Fig. 5.

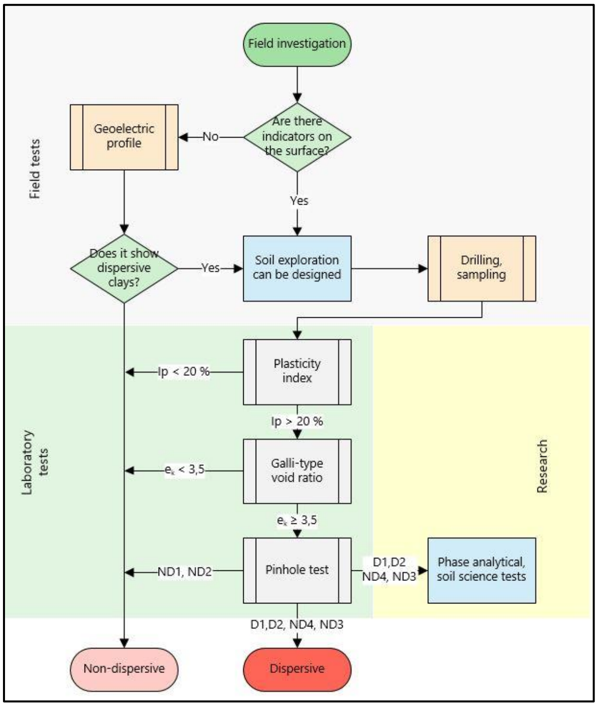

Figure 5. Recommended testing program for dispersive soil identification

Based on Fig. 5. large number of samples can be evaluated economically by following the steps of the flow diagram, which means after each test, the dispersive behavior can be ruled out, further testing is needed or the soil can be categorized as dispersive.

3 ASSESSMENT

After the soil is identified as dispersive the next task is to evaluate whether it can be used as fill material for embankment construction of flood protection structures or not.

One of the method to reduce the dispersive behavior is the soil treatment when the dispersive clay is mixed with some material that is changing the physico-chemical composition by strengthening the soil grain connection so the soil structure becomes erosion resistant (Nagy, Nagy, Kopecskó 2016; Ouhadi, Goodarzi 2006).

Another method for assessment is applying the method of soil mixing. This case there are no added chemicals, only non-dispersive soils are added to the soil that needs to be treated (Nagy, 2017).

Earlier experiences (Nagy 2017) showed that the dispersive behavior of a soil (identified by the pinhole test) can be treated by mixing it with non-dispersive soil.

A study (Nagy 2017) showed that if the mixture contains at more than 30% (measured in dry soil mass) dispersive soil, the mixture also behaves like a dispersive one, and at least 80% of non-dispersive soil is needed for a mixture to behave as a non-dispersive one.

This shows the importance of the effect, since the method would require large amount of soil removal in a case of an existing embankment, which would lead to great amount of earthworks and costs.

Therefore the soil mixing is suggested to be the method of reducing the dispersive behavior of the soil before construction, when the soil deposit which supposed to serve as fill material needs to be treated.

4 CONNECTIONS

This nature of the dispersive (clay) soils are leading to the necessity to monitor and evaluate dikes in order to prevent the failures due to the unfavorable properties of the soil.

Earlier experiences and studies (Nagy, Nagy, Kopecskó 2016; She et al. 2014) showed, that source of the behavior can be found in the examination of the physical and chemical properties, therefore several laboratory testing method were developed (ESP, SAR, EC, pH measurements, etc.) to get a better point of view on the properties of dispersive soils. This idea correlates with the idea of Mitchell (1974) which states the importance of the clay minerals in the soil structure.

Results showed that in many cases the dissolved salts and ionic composition of the minerals are leading to the unfavorable properties. These factors however, are also connected to an agricultural term sodic soils.

The chief characteristic of sodic soils from the agricultural stand point is that they contain sufficient exchangeable sodium to adversely affect the growth of most crop plants. For the purpose of definition, sodic soils are those which have an exchangeable sodium percentage (ESP) of more than 15. Excess exchangeable sodium has an adverse effect on the physical and nutritional properties of the soil, with consequent reduction in crop growth, significantly or entirely (Waskom et al 2014).

The soils lack appreciable quantities of neutral soluble salts but contain measurable to appreciable quantities of salts capable of alkaline hydrolysis, e.g. sodium carbonate. The electrical conductivity (EC) of saturation soil extracts are, therefore, likely to be variable but are often less than 4 dS/m (at 25 °C). The pH of saturated soil pastes is 8.2 or more and in extreme cases may be above 10.5. For sodic soils with pH higher than 8.0 there is a good estimation for the ESP value based on the pH of the saturated soil paste (Table 4.).

Table 4. Approximate ESP values based on soil pH (FAO 1988)

pH of saturated soil paste	Approximate ESP
8.0-8.2	5-15
8.2-8.4	15-30
8.4-8.6	30-50
8.6-8.8	50-70
8.8-	70

Based on Table 4. pH 8.2 can be referring to a soil which has an approximate ESP value of 15, what is enough to be called dispersive hence

DPIW (2009) suggests that ESP higher than 6.0 is enough to be susceptible of dispersion. This suggests that the dispersive behavior is the weaker criteria than the sodic at this standpoint.

To investigate the connection between the two terms, a two-way testing program was performed:

1. dispersive soils were tested by the methods of the sodic soil identification,
2. sodic soils were tested by the methods of the dispersive soil identification.

Laboratory test results showed that in many cases the dissolved salts and ionic composition of the minerals are leading to the unfavorable properties. These factors however, are also connected to an agricultural term sodic soils.

These are suggesting that there might be a relationship between the term "dispersive" and "sodic" soil. Not all dispersive soils are sodic and nor are all sodic soils dispersive, but there is an intersection between the two terminology (Fig. 6.).

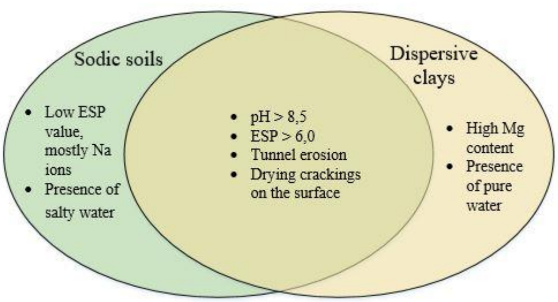

Figure 6. Relationship between dispersive and sodic soils

5 CONCLUSIONS

In geotechnical projects sometimes the factor of safety or the probability of failure cannot be determined by numerical methods. In such cases special construction technology regulations are made to rule out specific types of soils from available construction materials.

Dispersive clays are one of these risks, where the designing phase of an embankment cannot be done by some numerical method to ensure the obtained factor of safety.

In order to assure the safety of dikes (since the factor of safety cannot be determined due to tunnel erosion), the presence of dispersive clays has to be prohibited in the soil structure. Therefore to identify dispersive clays in embankments is vital, and for that specific testing is needed, because the standard geotechnical testing methods cannot distinguish the dispersive and the erosion resistant clays.

Several laboratory testing method were developed to get a better point of view on the properties of dispersive soils. Based on a large amount of experimental results, a testing program was constructed to give a decision tree for the evaluation.

Laboratory test results showed that in many cases the dissolved salts and ionic composition of the minerals are leading to the unfavorable properties. These factors however, are also connected to an agricultural term sodic soils. Earlier experiences and descriptions from literature both geotechnical and agricultural fields of study indicates that the term dispersive soild and sodic soil are connected.

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