COMPARISON OF THE PHYSICAL AND CHEMICAL PROPERTIES OF THE DISPERSIVE AND SODIC SOILS

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ABSTRACT. Comparison of the physical and chemical properties of the dispersive and sodic soils - Some cohesive soils show very little resistance when it comes to interaction with relatively pure water, however the water flow itself does not have to necessarily cause any damage in the soil structure. These soils are so poorly bonded, that this small amount of water flow can lead to structural breakdown. The effect caused several dike and earth dam damages and failures in the past years, therefore the behavior itself is considered as a geotechnical risk in the process of design. The dike breaches lead to the emergence of knowing how to identify and locate the areas and soil types, where the hazardous soils occur.
In geotechnical engineering these soils are referred as dispersive soils, and their properties are known since the 1960s. In the recent years researches were carried out to get a better point of view of the reasons of these kind of behavior. Therefore the investigation of physical and chemical properties were made.
The results showed that the dispersive behavior can be connected with the amount of dissolved salts in the soil extract. Since these are known as the origin of sodic soils, the relationship was investigated.

Key-words: dispersive soil, sodic soil, physico-chemical composition, pinhole test, geotechnical risk, geotechnical engineering

1. PROPERTIES OF DISPERSIVE CLAYS

In geotechnical engineering, clay soils are mostly considered to be a highly resistant to erosion by flowing water, and therefore their usage in dikes as a water-tight material was an ordinary method. Structural dams were constructed where some clay (which was known as watertight material) was used as a core material to prevent leakage problems and ensure the safety of the downstream face of the dike.

However in some cases leaking and seepage occurred in the presence of relatively pure water. Those cases often lead to dike breaches, resulting the failure of the structure. Those failures were often related to heavy rainfalls, or associated

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with the changes of the water level on the upstream face of the dike (Sherard, 1972).

These unusual clay soils are called dispersive clays where the physico-chemical composition of the soil cause clay particles to deflocculate in the presence of relatively pure water (ICOLD, 1990). This deflocculation is the dispersion, and the presence of the water could be a rainfall and the runoff on the surface of the dike. The energy of this amount of flowing water can force the poorly ponded clay particles to dissociate, leading to a suspension-like state.

Not only dispersive behavior can lead to dike breach or failure, therefore the identification of different soil types and the related form of failure can vary. Table 1 contains the erosion types and the soil types related to them.

Table 1. Types of internal erosion (Nagy, 2014)

Phenomenon	Effect	Type of soil
Dispersion	Physico-chemical composition	Fine grained soils
Suffosion	Instable soil structure	Gap graded soils
Piping	Pore water pressure rises	Fine graded, non-cohesive soils

Several failures and dike breaches were associated with the presence of dispersive clays. The largest in the Hungarian experience is the one was detected in the Körös valley in 1980. The dike along the river Sebes-Körös was constructed in 1978 with a height of 3-4 meters. The flood in 1980 was the first large water load which the dike suffered. The near 3 meters large flood load caused several leakages along the dike, in the early morning. At noon, the soil structure could not bear any more load, the dike breach occurred on a 52 meters long section of the dike (Szepessy, 1983).

Later, the geotechnical report identified the critical soil layers, as highly, D1 dispersive, and it stated, that the dike breach was due to the structural breakdown and not because of the subsoil outwashing like in the case of a piping failure. The reasons of the breach were the following:

- presumably the lower soil layers were not compacted well enough, which allowed water to flow through the soil pores,
- the water flow in a dispersive soil layer is leading to excessively accelerating erosion.

Figure 1. Dispersive soil after the flood in 1980

1.1. Origin, factors of emergence

Aforesaid reasons require to examine these kind of soils, and their behavior, however dispersive clays have not been associated with any specific geologic origin, but most encountered to date have been found as alluvial clays in the form of slope wash, lakebed deposits, loess deposits, and flood plain deposits.

Many cases, dispersive soils are associated with (DPIW, 2009):

- moderately steep (>10°) slopes,
- areas with less than 650 mm annual rainfall,
- areas, where seasonal, or highly variable rainfall combined with high summer temperature,
- cracking of surface soils due to desiccation.

While the mentioned factors were describing the climatic and topographic conditions of the Tasmanian dispersive clay soils, the similarities with the Hungarian experiences are undeniable. Figure 2 shows the average annual rainfall and average annual mean temperature maps of Hungary. Most of the cases, when damages of dikes were experienced due to the presence of dispersive clays were located at the circled areas in Figure 2.

The circled areas represent the large part of the Hungarian Great Plain. Rivers Tisza and Körös are flowing through these sites, and dikes running by them were found to be constructed from dispersive material. On the surface of the examined dikes the mentioned surface cracking was discovered, often leading to the development of tunnels in the structure, where during a rainfall water can cause the tunnel erosion.

Figure 3 shows two kind of appearance of these crackings. The left one is the cracking on the dam crest, which is mostly the result of the temperature variation (drying and shrinking).

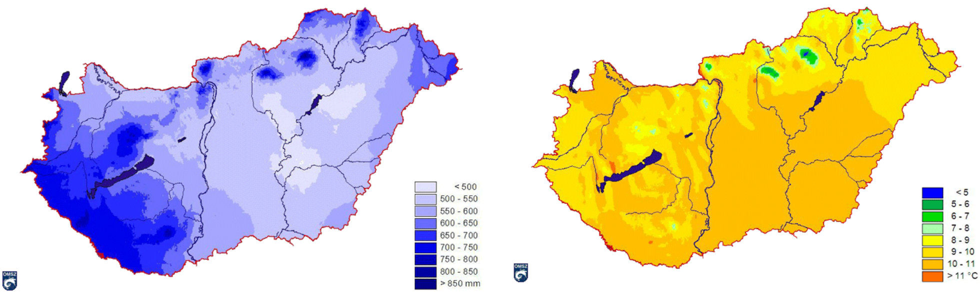

Figure 2. Average annual rainfall and mean average annual temperature maps of Hungary (source: www.met.hu)

The right one is a result of the surface cracking, when the tunnel which is developing in the soil structure due to the surface cracking, will lead to some larger holes in the structure of the dike (Nagy, 2014)

Figure 3.Surface cracking of a dike, and erosion hole on the edge of the dike crest

1.2. Sodicity and dispersion

As the dispersive behavior is connected to the physico-chemical properties, the composition of these kind of clays are often examined. Sherard in the 1950's recommended a method based on the amount of the exchangeable sodium in the soil compared to the total dissolved salts (TDS), resulting to a categorization of the dispersive behavior (Figure 4. after Sherard) as:

- dispersive
- intermediate
- non-dispersive.

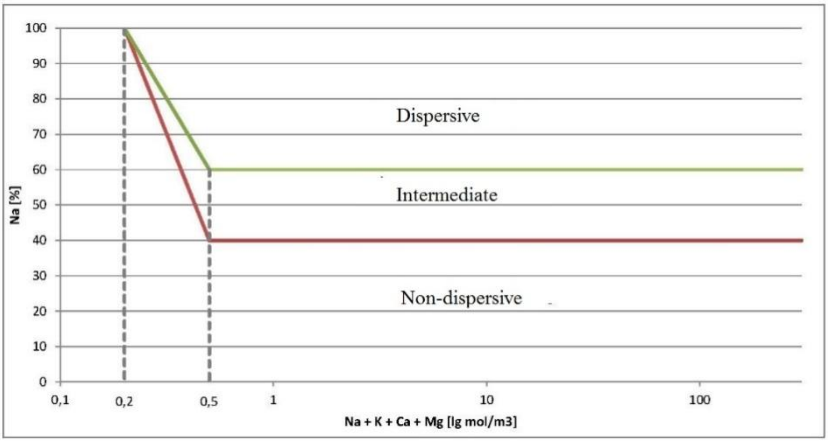

Figure 4. Dispersive categories based on the amount of exchangeable sodium (After Sherard)

However, the method requires at least 60% of the exchangeable cations to be sodium. Researches (Zorluer et al. 2010) showed that with less sodium than Sherard's method suggests, dispersive behavior was observed. One explanation can be the presence of anions bonded to the cations.

Based on the DPIW (2009) the tunnel erosion which is connected to dispersive behavior occurs with greater than 6.0% ESP, where ESP is:

$$ESP = \frac{Na}{(Ca + Mg + K + Na)} \cdot 100 \qquad (1)$$

the exchangeable sodium percentage. It worth mentioning that the denominator is basically the amount of the total dissolved salts.

Since the 1960's the presence of exchangeable sodium in the soil is considered as the main contributing chemical factor in the dispersive behavior (ICOLD, 1990). In the earlier researches more than 10% of ESP was considered as dispersive behavior, but based on DPIW the lower value, 6.0% is enough for further testing, or investigation of the material.

The explanation can be found in the properties of the clay minerals. In slightly saline water, sodic soils swell, but generally do not disperse. The clay platelets remain intact. The presence of salts within the soil water reduces the osmotic gradient between the outside and inside of the clay platelets preventing the ultimate stage of swelling leading to dispersion (Nelson, 2000). Maintenance of salts within the soil water is one of the most important mechanisms by which sodic soils are protected from dispersion and development of tunnel erosion. Many reasons are leading to the assumption that there might be some connection between the dispersive and sodic soils.

2. PROPERTIES OF SODIC SOILS

Saline soil is an agricultural term, referring to a soil which went under the process of increasing the salt content known as salinization. Salinization can be caused by natural processes such as mineral weathering or by the gradual withdrawal of an ocean. It can also come about through artificial processes such as irrigation.

The saline content and the surface of sodic soils are leading to an assumption that there might be a relationship between the term sodic soil and dispersive soil. She et al. (2014) suggests, that the increasing of the sodicity of soils or decreasing the salinity of the soil solution increases the repulsion forces between clay particles.

Pratt and Suarez (1990) showed, that the sodicity and salinity values can result the dispersion or swelling the clay soil. This enhances the process of aggregate breakdown, and if it is combined with heavy runoff, it increases the erodibility of 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. 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 2).

Table 2. Approximate ESP values based on the pH of the saturated soil paste (FAO Soils Bulletin #39, 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 2 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 suggests that ESP higher than 6.0 is enough to be susceptible of dispersion. This suggests that the dispersive behavior is a weaker criteria than the sodic at this standpoint.

3. LABORATORY TESINTG OF THE DISPERSIVE BEHAVIOR

Several methods are available for testing. Field testing, like the crumb test, or the drop test (Ghurman et al. 1977) can give a quick, but not so precise guide in the evaluation of dispersive clays, however, the first step of the identification is to locate the dangerous sections of the dikes. For that purpose, the easily performed tests are the best choices. These simple field testing methods are capable to give a rough estimation of the suspected dispersive behavior of the soils, based on them samples can be collected for more accurate laboratory testing.

The most recognized laboratory tests is the pinhole test. The method and the device was developed by Sherard et al. (1976). The device and the method is based on a hydraulic approach.

For the test a compacted (mostly with a Proctor device) cylindrical specimen is needed. The method simulates the flow of water through a crack by punching a 1.0 mm diameter hole in the specimen with an iron pin, and distilled water can percolate through it. If the sample is a dispersive clay, the flow breaks down grains from the soil structure, and the flowing water becomes a dispersive solution.

The equipment is capable of modelling different hydraulic conditions, therefore 4 different pressure heads can be applied, 50, 180, 380 and 1020 mm. Dispersive clays erode at the smaller heads, consequently erosion-resistant soils can withstand 1020 mm water pressure without major particle movements. During the test, the flow velocity, and the eroded grains are observed. The device can be seen in Figure 5.

The H stands for the pressure head, which is applied on the sample. This potential will start the seepage, and increasing the applied value causes a higher level of hydraulic pressure to the soil structure, and a larger flow velocity. The output of the test is a classification based on the method after Sherard et al. (1976) (Table 3).

Table 3. Dispersive soil categories

Non-dispersive	Transitional	Dispersive
ND1, ND2	ND3, ND4	D2, D1

Based on Sherard (1976), the D1 and D2 dispersive categories are representing soils which are capable of suffering piping failure and severe erosion damage due to rainfall in earth dams and embankments, the ND1 and ND2 classifications are the non-dispersive erosion resistant soils, which are applicable for embankments.

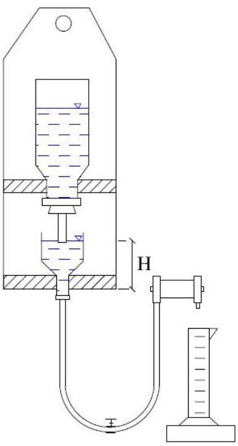

Fig. 5. Pinhole test device

The intermediate classifications, ND3 and ND4 indicate soils with potential of behaving like the dispersive soils, but the rate of erosion is lower compared to soils from D1 or D2 categories.

While the method itself gives a simple classification, the measurement is based on a hydraulic criteria, therefore other laboratory testing is advised in order to have an accurate result. During the research the categorization based on the pinhole test was used in all cases.

4. LABORATORY TESING OF THE SODIC BEHAVIOR

Based on Waskom et al. (2014) the main causes of saline soils are measurable by electrical conductivity (EC), pH, and high sodium content. Therefore the laboratory testing is based on the measurement of these three.

All testing was performed on a soil suspension prepared by the following order:

- Soil samples are dried in 105°C in a heating oven.
- 30 grams of the soil are weighted out with grain size less than 2 mm-s.
- The dry soil is mixed with 75 cm^3 of boiled distilled water to create a 1:2.5 proportion suspension.
- The soil suspension is at rest for 24 hours.

After the 24 hours three testing method can be performed in the following order:

- measurement of electrical conductivity;measurement of pH; measurement of pNa.

Different order of measurement can lead to misleading results, because during the measurement of pH ions can get to the solution, which leads different value of the EC, therefore the electrical conductivity testing has to be the first to perform.

Before the measurement takes place the suspension has to be shaken to prevent any sedimentation which can stick to the measuring head, and giving an inaccurate result. Figure 6 shows the equipment with the measuring unit. The measurement of the pH value is performed with the same equipment but different head.

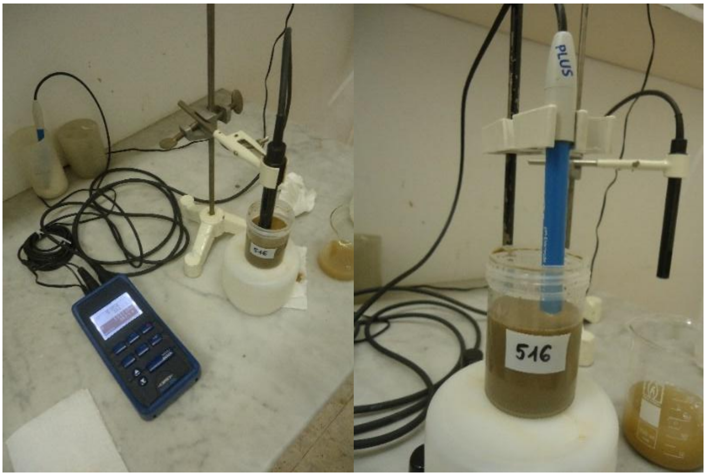

Fig. 6. EC measuring equipment(left) and different head to measure the pH (right)

5. SOIL SAMPLING, RESULTS

The measurements were carried out on two groups of samples.

- soil samples collected from dikes and earth dams (located in the circled area on Figure 1).
- soil samples which were treated by slaked lime to change the dispersive behavior.

As the first chapter mentioned the basic idea is that the dispersive behavior of the soil can be related to the clay minerals, the physico-chemical properties. For that, we examined, whether the change of the chemical properties of the soils, can decrease the dispersive behavior. For that laboratory tests were carried out. With two groups of soil samples taken from the Hungarian Great Plane, we added different amount of slaked lime (Nagy 2015).

First we needed to know if the soil we are using is dispersive or not. So the first step was to determine the category of dispersion based on Sherard (1976). Samples were found to be in D2 dispersive. First, we added 2.5, 4.0, 6.0 and 8.0 weight percent slaked lime, and compacted the specimens with the Proctor device. After 48 hours rest, pinhole tests were carried out, and the results showed that even with 2.5% slaked lime the soil was classified as ND1, the least dispersive category.

This led to the recognition, to reevaluate the amount of added lime. Therefore in the second phase of the research, 1.0, 1.5, 2.0, 2.5 weight percent slaked lime was used.

The second group of samples showed different dispersive categories, but the tendency matches the one observed in the first group. Overall 21 soil samples were examined, 13 of them belonged to the first type of samples, and 8 were treated with slaked lime.

Table 4. Results of the measurements

Dispersive category (based on pinhole test)	**pH [-]**	**pNa [-]**	**EC [mS/cm]**
D1	8,76	2,36	0,760
D2	8,93	2,32	0,869
ND4	8,48	2,03	1,051
ND3	8,43	2,23	1,345
ND2	N/A	N/A	N/A
ND1	9,78	2,29	1,050

In order to have a better view on the results it has to be mentioned, which samples were found to be highly dispersive or non-dispersive. The ND1 category is containing samples, which were treated by slaked lime, therefore the results measured on those samples have to be discussed separately from the ones taken from dikes.

If we accept this statement, the following can be said:higher pH value was measured when the soil was categorized as dispersive (D1, D2);higher pH value was measured when the soil was categorized as dispersive 1, D2);higher EC value was measured when the soil was categorized as non-dispersive or intermediate (ND4 or less dispersive).

6. CONCLUSIONS

In geotechnical engineering clays are considered as a watertight and erosion-resistant materials, therefore their usage in dikes and earth dams as a fill material to prevent seepage, and leakage problems on the downstream face of the dikes are widely used.

In some cases these cohesive soils behave in the presence of water like there were little bonding between the clay platelets, and the flow of the water can be enough force to break down the soil structure and begin to erode the dike. These unusual soils are referred as dispersive soils, and their biggest disadvantage is the likelihood of erosion due to rainfall or surface runoff.

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 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.

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.

Laboratory tests were carried out in order to get information about both the dispersive and sodic properties of the soil samples. Two groups of samples were used, one with samples taken from dikes, the other with samples known as dispersive soils, treated by slaked lime. All of the samples were tested by Sherard's pinhole test, to know their dispersive categories, and later chemical test, pH, pNa and EC measurements were carried out to compare the dispersive and sodic soil properties.Results showed that soils, which were described as dispersive (D1, D2) have pH high enough (8.76-8.93) to characterized as sodic soils ($pH > 8.2$). The measurement of the electronic conductivity showed that the dispersive, and even the intermediate category soils have less average EC value, as the upper limit of the sodic soil categorization ($EC < 4.0$). Therefore based on our experiences the dispersive and sodic terms for a soil can be associated, the test results showed that for these soils the criteria to be categorized as sodic soil are stronger conditions as it is in the case of the dispersive soils.

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