

# Identification and Treatment of Erodible Clays in Dikes

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**Abstract.** When it comes to flood protection, the established method is to use impermeable material in dikes, to prevent seepage. This material is usually some kind of clay soil which is considered as impermeable and erosion-resistant. Despite that, in many occasions not only seepage, but the failure of the dam occurred due to surface erosion, because these kinds of irregular soils are barely investigated, and their presence are not considered during the phase of designing.

In geotechnics these soils are called dispersive clays, and their greatest hazard is that they are not distinguishable at sight or by the standard geotechnical tests from the regular erosion-resistant clays, therefore many dams are built by these kind of materials, causing extra risk when it comes to evaluating the probability of failure. The reason for this kind of behavior can be found in the structure and the distribution of the clay minerals which are building up the soil.

Based on earlier experiences and papers it is possible to reduce the magnitude of erosion by mixing the soil with slaked lime. First to evince the dispersive nature of the soils we developed a testing program. Therefore we collected samples from the Great Hungarian Plane, and identified them by the pinhole test after Sherard. If the soil was identified as a dispersive clay, slaked lime was mixed to it, and the test was performed again to see if the soil became less dispersive, therefore more erosion-resistant or not. The main goal was to find an optimal value of the added lime.

The main chapters the paper present the background of the dispersive soils, and the mechanism of failure, the tunnel erosion. Shortly the laboratory testing methods are demonstrated, and the way feedback affects the further tests, and the results of the treatments, the changes of the degree of dispersion are shown.

**Keywords.** Dispersive clay, pinhole test, geotechnical risk, soil treatment

## 1. Introduction, Properties of the Dispersive Clays

The term ‘dispersive clay’ refers to special clay soils, where the physico-chemical composition of the soil can cause clay particles to deflocculate in the presence of relatively pure water (ICOLD, 1990).

This deflocculation is the phenomena called dispersion in this case, and the presence of the water could be the effect of a rainfall. Thus it can produce enough energy to dissociate poorly bonded clay particles, and enable the erosion of the dike, rapidly leading to the failure of it.

### 1.1. Surface erosion

The mechanism of failure is the surface erosion. The term refers to the initial cause, namely that the rainfall can produce small tunnel-shaped cavities on the surface of the embankment, which opens the soil structure allowing water flowing through. In this case a concentrated leak is creat-

ed on the downstream side caused by the water flowing through the pores of the soil. The erosion starts at the end of the leak, and as it is progressing to the upstream face a tunnel-shaped passage is formed. It is the result of the deflocculation, and not the seepage, like in other erosion problems (ICOLD, 1990).

However the phenomena itself and the leakage on the downstream face is similar to the cases of piping or suffusion, there are different types of soils which are susceptible for the different failure mechanisms, as it can be seen in Table 1. As it shows, piping is very similar to the dispersive behavior, but in that case, the soil is fine-graded, it has no cohesion (L. Nagy, 2014).

**Table 1.** Types of internal erosion, L. 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

Clay soils are susceptible of volume change depending on the amount of pore water, and the external temperature. During a warm period, drying cracks can develop on the surface of the dike, in which during a rainfall water can get inside the soil structure. Figure 1. shows the downstream face of a dam, where the outwashed grains are sedimented at the toe of the downstream slope.



**Figure 1.** Soil grains washed out from the dike

This small amount of energy can dissociate the clay particles, and by the water flowing through the crest of the dike in the direction of the downstream face, a leakage will be created, and soil grains will settle nearby. The erosion tunnel created by the drying crack provides a way for the water to overpass the dike, and during that more and more soil grains will be washed out by the energy of water flowing through.

The process is self-accelerating. With a wider tunnel the amount of water and the erosion increases. Therefore the identification of these kinds of clays, and the treatment needs to be done quickly after the concentrated seepage and the outwashed grains are found at the downstream face of the structure.

## 2. Identification

First, to identify the problem it is important to find the hazardous places. Fortunately there are

some signs on the surface of the dikes which indicate the presence of dispersive soils (G. Nagy, 2014). The earlier mentioned drying cracks are one way to find suspicious places, but more adequate identification methods are available. Figure 2 shows a typical surface crack.

These cracks can provide the start of the tunnel and the beginning of the erosion, especially in those cases, when the crest of the dam is not covered with pavement or carriageway.



**Figure 2.** Surface drying crack

There are two ways to identify the problem: field tests, and laboratory tests. Field testing can be relevant, when a concentrated leak is discovered on the downstream face, and quick intervention is needed. Laboratory testing can be used as part of the designing process, to evaluate materials behavior in terms of tendency of internal erosion. The next chapter focuses on one of the most known identification method, the pinhole test.

## 3. Laboratory Testing, Pinhole Test

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 3.

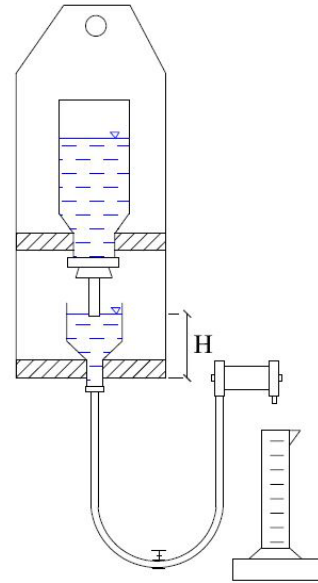
The  $H$  stands for the pressure head, which is applied on the sample. This potential will start the seepage, and increasing the applied value causes a higher level of hydraulic pressure to the soil structure, and a larger flow velocity. The output of the test is a classification based on the method after Sherard et al. (1976) (Table 2).

**Table 2.** 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. The intermediate classifications, ND3 and ND4 indicate soils with potential of behaving like the disper-

sive soils, but the rate of erosion is lower compared to soils from D1 or D2 categories.



**Figure 3.** Pinhole test device

#### 4. Correlation with the Atterberg Limits

The identification of the dispersive clays is necessary, because the standard tests (e.g. plasticity index) are inappropriate for determining whether a soil is susceptible to erosion or not.

Atterberg limits give no indications for dispersive clays. Based on field reports, papers and earlier experiences, the correlation between the rate of dispersion and the plasticity index in Hungary can be seen in Figure 4. The blue and yellow columns are representing the high and medium plasticity clays, the grey is for the low plasticity clay. Table 3 shows the frequency of each categories.

As it was mentioned in the first chapter, the dispersion is a characteristic of fine-grained soils. Figure 4 confirms that, only 3 soils were granular in the dispersive and transitional categories, and only 7 of them were silts. These few examples of the total 387 shows that the first statement is true, and dispersive behavior is considerable only with clay soils.

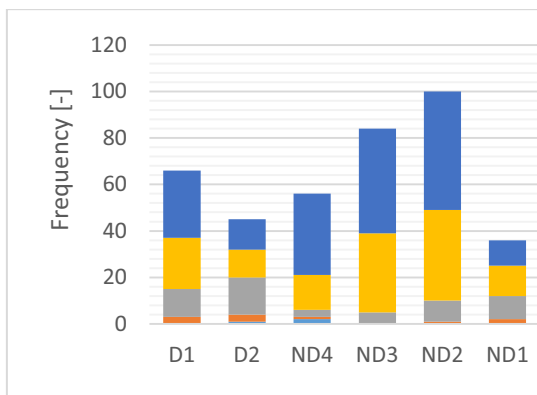


Figure 4. Dispersive behavior of different soil types

Table 3. Frequency of the different categories

Plasticity index [%]	D1	D2	ND4	ND3	ND2	ND1
0-10	0	1	2	0	0	0
10-15	3	3	1	0	1	2
15-20	12	16	3	5	9	10
20-30	22	12	15	34	39	13
>30	29	13	35	45	51	11
<b>Total</b>	<b>66</b>	<b>45</b>	<b>56</b>	<b>84</b>	<b>100</b>	<b>36</b>

It shows that in Hungary the medium, and high plasticity clays are susceptible mostly when considering dispersive behavior, although it also can be seen, that the plasticity index itself is not enough to determine whether a soil is capable of tunnel erosion or not. That seems to confirm the the characterization as ‘dispersive clay’, but it cannot be said that clays with a plasticity index higher than 20% are all dispersive. Note, that Sherard et al. (1972) mentioned, that in Australia the dispersive clays are mostly low or medium plasticity clays.

## 5. Treatment of Dispersive Clays

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.

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).

Both sample groups were found to be in D2 dispersive. To the first group, 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 less dispersive category.

This lead 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. The results are represented in table 4.

Table 4. Treatment of dispersive soils

First group	Second group	Dispersive category
0.0% added lime	0.0% added lime	D2/D2
-	1.0% added lime	ND4
-	1.5% added lime	ND3
-	2.0% added lime	ND1
2.5% added lime	2.5% added lime	ND1/ND1
4.0% added lime	-	ND1
6.0% added lime	-	ND1
8.0% added lime	-	ND1

The 1.5 weight percent added lime decreased the rate of dispersive behavior to a transitional category, the 2.0 weight percent led to a non-dispersive ND1 category. Forsythe (1977) investigated the needed amount of lime to reduce the dispersive behavior, and his result showed that 0.5-3.0% slaked lime could be enough.

The effect of the treatment on the plasticity of the clays was also measured. The result are presented in Table 5.

**Table 5.** Changes in the plasticity index

First group	Plasticity index	Second group	Plasticity index
0.0% added lime	29.42%	0.0% added lime	30.01 %
-	-	1.0% added lime	36.25%
-	-	1.5% added lime	38.86%
-	-	2.0% added lime	33.76%
2.5% added lime	44.97%	2.5% added lime	28.29%
4.0% added lime	30.35%	-	-
6.0% added lime	18.71%	-	-
8.0% added lime	15.61%	-	-

The 8.0 weight percent of added lime changed a high plasticity clay to a low plasticity clay, while in the second group, the maximum used lime amount changed a high plasticity clay to a medium plasticity clay. Supposedly the 8.0% would also change the plasticity index so that it would also become a low plasticity clay.

## Conclusions

In geotechnical projects where the material properties are unclear or may change the probability of failure cannot be determined by numerical methods. In such cases special construction technology regulations rule out such types of soils from available construction materials. Dispersive clays are one of these materials

For dikes the presence of dispersive clays has to be prohibited in the soil structure. Therefore it is vital to identify them, and for that specific testing is needed, because the standard geotechnical testing methods (e.g. uniaxial compression test) and basic properties (e.g. Atterberg limits) cannot distinguish the dispersive and non-dispersive soils.

The identification of dispersive clays is a multi-faceted assessment process, where none of the methods of the identification ensures 100%

certainty. The pinhole test is a well-used method, but for the certainty, it should be confirmed by other techniques, such as the geoelectric measurements, or the standard void ratio (G. Nagy, 2014).

When the crucial soils or layers are identified, one way of the treatment is the mixing with slaked lime. The change of the rate of the dispersion can be measured, and 1.5-2.0% of slaked lime added could change a dispersive clay into a non-dispersive (ND1) erosion-resistant clay. It should be noted, that the amount of lime needed depends on the soil itself which is treated, based on the different clay minerals which is building up the soil structure.

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