Effects of density, moisture content and curing time on dispersivity and erodibility of two River Nile deposits

Effets de la densité, composants (contenu) de l'humidité et le temps de traitement sur la dispersivité et de l'érodibilité de deux dépôts du fleuve du Nil

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ABSTRACT

Piping failure is among the most common failure modes for embankment dams. It is often related to the potential of the embankment material to de-flocculate and erode in the presence of water. Soil erosion is therefore one of the main factors affecting the safety and serviceability of earth structures. This paper presents the results of a laboratory testing program intended to study the effects of dry density, moisture content and curing time on the erodibility and dispersivity of two alluvial deposits aimed to be used as dam core material. One sample is a recent deposit obtained from the flood plains of the River Nile in Northern Sudan (Soil A) while the other (Soil B) is obtained from an adjacent area in the upper terraces of the Nile. Preliminary evaluation has shown that Soil A is slightly dispersive while Soil B is highly dispersive.

Specimens from the two samples were prepared in the laboratory at different moisture and density conditions and tested for dispersivity and erodibility using the pinhole test. Identical specimens were prepared, cured for different periods of time extending up to 18 months and tested. The results have shown that the erosion resistance of the slightly dispersive Soil A improved with increase in dry density when the moisture content is wet of optimum and with curing time for specimens with lower density and moisture content. However, the highly dispersive Soil B did not show significant improvement of its erosion resistance, neither with increase of its density nor with increase in curing time.

RÉSUMÉ

L'échec de pompage est le plus courant parmi les échecs des digues des barrages. Il est souvent lié au potentiel des matériaux des digues a de s'accumuler et s'éroder dans la présence de l'eau. Erosion du sol est alors l'un des facteurs majeurs affectant la sécurité la serviabilité des structures de la terre. Cet article présent les résultats des essais d'un programme de laboratoire essayant d'étudier les effets de densité sèche, composants de l'humidité, et le temps de traitement sur dispersivité et de l'érodibilité de deux dépôts destinées à être utiliser comme noyau de matériaux pour barrage. L'un des échantillon est une dépôt récent obtenu des plaines des inondations du fleuve du Nil au nord du Soudan (Sol A), tandis que l'autre (Sol B) est obtenu d'une zone adjacente des hautes terrasses du Nil. E premier lieu, l'évaluation a montré que le sol (A) est légèrement dispersif tandis que le Sol (B) est hautement dispersif.

Des spécimens des échantillons ont été préparés au laboratoire à de différentes conditions d'humidité et de densité et sont essayés pour dispersivité et de l'érodibilité utilisant le teste du pinhol. Des spécimens identiques ont été préparée, séchées pour de temps différents allant à 18 mois et sont essayées. Les résultats ont montrés que la résistance de l'érosion du Sol (A) qui est légèrement dispersif, s'améliore en augmentation en densité sèche lorsque le contenu de l'humidité est mouillé (humide) de l'optimum et avec le temps de traitement des spécimens avec densité baissée et contenu de l'humidité. Toutefois, le Sol (B) qui est hautement dispersif n'a pas montré d'amélioration important de ses résistances de l'érosion, ni avec l'augmentation de ses densité ni en augmentation du temps de traitement.

Keywords: dispersive soils, erosion resistance, curing time, River Nile deposits

1 INTRODUCTION

Soil dispersivity can be defined as the natural tendency of clayey soils to disperse (deflocculate) in the presence of water. Dispersive soils deflocculate easily and rapidly without significant mechanical assistance in water of low-salt content, and are therefore highly erodible. Dispersive soils are generally not different in appearance and index properties from non dispersive soils which are only eroded with some mechanical agitation caused by velocity of the eroding water. Dispersive soils usually have a high proportion of their adsorptive capacity saturated with sodium cation. Thus, they are identified chemically by quantifying the amounts of sodium cations in relation to other cations in the surface of the clay particles and in the pore water.

The difference in the erosion behavior of dispersive and non dispersive soils (Sherard et al 1974) results from the fact that for non dispersive soils there is a definite threshold velocity below which flowing water causes no erosion. For dispersive soils, there is no threshold velocity to start erosion. The colloidal clay particles go into suspension even in quiet water and being therefore highly susceptible to erosion and piping.

The mechanism by which a dispersive soil is eroded involves the structure of the soil in one hand and the character of the interaction between the pore water and eroding fluids on the other hand (Elges 1985). The presence of exchangeable sodium is an important factor contributing towards dispersive behavior in soils. This is expressed in terms of the exchangeable sodium percentage (ESP). One of the main properties which also claimed to govern the susceptibility of clay to dispersion is the total content of dissolved salt in the pore water and the eroding water (Sherard et al 1976). The lower the content of dissolved salts in the pore water and the eroding water, the greater is the susceptibility of sodium saturated clays to dispersion.

Problems associated with dispersive soils include gully erosion and failure of soil to perform adequately as a construction material. Piping of material initiated by dispersion of clay particles along cracks and fissures and propagated by

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seepage water, often causes total failure of slopes of natural deposits and more seriously of earth dams and embankments.

2 IDENTIFICATION OF DISPERSIVE SOILS

Since a dispersive soil does not lend itself to be identified by the range of conventional tests usually employed by the soil mechanics laboratories, some specialized tests have been developed in order to assess the dispersivity of the soil. These can be divided into physical and chemical tests. The physical tests show the effect of dispersivity of the soil, that is, the natural susceptibility of the soil to deflocculate in the presence of pure water. The most common physical tests used for this purpose are: crumb test, double hydrometer test and pinhole test.

The crumb test is the simplest of the physical tests and indicates the tendency of the soil to deflocculate in the presence of distilled water. It consists of placing crumbs of soil into a beaker of distilled water, or 0.05 M NaOH solution, and noting the reaction as the soil begins to hydrate. The crumb test gives a rapid good indication of the dispersivity of the soil.

The double hydrometer test is one of the first methods developed for soil dispersivity assessment. In this test, the particle size distribution is first measured using the standard hydrometer test, in which the sample is dispersed in the hydrometer bath with strong mechanical agitation and a chemical dispersant. A second hydrometer test is made without strong mechanical agitation and without a chemical dispersant, and hence shows less colloidal particles than the first test and is a measure of the clay to disperse naturally. Percent dispersion is the ratio of clay size particles in the two tests.

The pinhole test has been developed by Sherard for direct measurement of the dispersivity and erodibility of compacted fine-grained soils. In this test, distilled water is caused to flow through a 1 mm diameter hole formed in a specimen of compacted clayey soil. Dispersivity is assessed by observing effluent color and changes of flow rates through the hole, in addition to the visual inspection of the diameter of the hole after completion of the test. The water emerging from dispersive clay carries a suspension of colloidal particles, while the water from erosion-resistant clay is crystal clear. The details of the test apparatus and procedure are included in ASTM D4647–93 and BS 1377: Part5:1990. The test results can be categorized into one of the six categories: the dispersive categories, D1 and D2, and the non-dispersive categories, ND1, ND2, ND3 and ND4.

The chemical testing for soil dispersivity has the purpose of indicating the amounts of the cations in the soil structure, namely, sodium (Na), calcium (Ca), magnesium (Mg) and potassium (K), with special emphasis to the sodium and its relative present. Both exchangeable cations on the surfaces of clay minerals and saturation extract cations of the pore water are usually determined. The exchangeable cations are measured in terms of milliequivalent per 100 gm of dry soil and are expressed as (CEC). Then the exchangeable sodium percentage (ESP) is calculated from the amount of sodium on the exchange complex. (Elges 1985) suggested a threshold ESP value of 10%, above which soils that have their free salts leached by seepage of relatively pure water are prone to dispersion. According to (Gerber & Harmse 1987), soils with ESP values above 15% are highly dispersive.

In the pore water salts testing, the amounts of the main metallic cations in solution (calcium, magnesium, sodium and potassium), are determined in terms of milliequivalent per liter. The total dissolved salts (TDS) equals to the sum of these four cations. The sodium adsorption ratio (SAR) is also calculated from the amounts of sodium, calcium and magnesium cations. The SAR is used to quantify the role of sodium when free salts are present in the pore water (soils with TDS greater than 40 milliequivalent per liter). If no free salts are present the use of SAR to help define dispersive soils is not applicable. However, even soils with high TDS, which are initially in a flocculated state, can become dispersive if the salts are leached out.

3 THE LABORATORY STUDY

For the purposes of the laboratory study two soils (Soil A and Soil B) were selected from sources proposed to be used as core material for a dam project in Northern Sudan; Soil A was obtained from the flood plains of the River Nile while Soil B was collected from adjacent upper terraces of the Nile. The two studied soils were stored in well sealed drums to prevent drying out. Conventional classification tests and compaction tests were performed on the two soils. As shown in Table 1, Soil A and Soil B are classified as low plastic silt and low plastic clay, respectively.

Table 1. Classification of Soil A and Soil B

Sample	M.C (%)	L.L (%)	P.L (%)	P.I (%)	Fines (%)	Classification (USCS)
A	21.3	37	25	12	81.4	ML
B	10.0	43	25	18	61.4	CL

The Standard Proctor test was conducted for both soils and has shown that their compaction parameters are more or less the same, 21 % OMC and about 16 KN/ m^3 MDD.

The two soils were tested for dispersivity by the pinhole test, the double hydrometer test and the crumb test as well as chemical testing for exchangeable cations (CEC and ESP) and pore water cations (SAR).

The results of the pinhole test and the crumb test are shown in Table 2. The results of the chemical dispersivity testing are presented in Table 3. Figure 1 and Figure 2 show the results of the double hydrometer tests for Soil A and Soil B, respectively. Soil A is non dispersive from the results of the pinhole and the crumb tests while it is slightly to moderately dispersive from the results of the double hydrometer and the chemical tests. The results of all dispersivity tests for Soil B showed that it is highly dispersive.

Table 2. Results of Pinhole and Crumb Tests

Sample	Pinhole Test Result	Crumb Test Result
A	ND1	Grade 1 (No Reaction)
B	D1	Grade 3 (Moderate Reaction)

Table 3. Results of the Chemical Dispersivity Testing

Sample	CEC (m. equivalents per 100 gm)	ESP (%)	SAR ((m. equivalent/ Liter)^0.5)
A	34.5	13.0	13.8
B	41.3	42.7	43.0

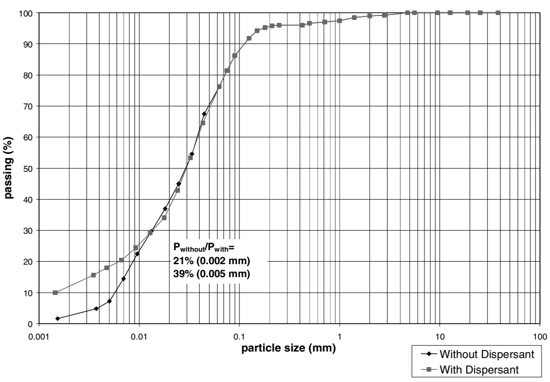


Figure 1. Double hydrometer test result for Soil A

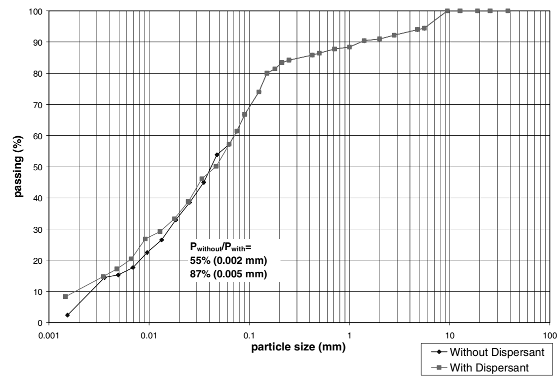


Figure 2. Double hydrometer test result for Soil B

Each soil was divided into 6 groups (A1 to A6 and B1 to B6 as presented in Table 4). Each group was prepared at the same moisture content and dry density. More than six identical test specimens were prepared from each group for pinhole testing. The adopted dry densities were either 88% or 95% or 105% of the Standard Proctor MDD, while the adopted moisture contents were in the range of (OMC-2.1) % to (OMC+2.9) % for Soil A and (OMC-4.3) % to (OMC+3.7) % for Soil B. These ranges may fairly be considered to include the normal and probable ranges for implementation of most earth fill works.

Table 4. The selected moisture contents and dry densities

Soil A					Soil B				
OMC= 20.6%, MDD= 16.20 KN/m^3					OMC= 21.3%, MDD=16.13 KN/m^3				
sample	MC (%)		DD (KN/m^3) % of MDD		sample	MC (%)		DD (KN/m^3) % of MDD	
A1	18.5	OMC-2.1	17.05	105	B1	17.0	OMC-4.3	16.91	105
A2	18.5	OMC-2.1	15.39	95	B2	17.0	OMC-4.3	15.32	95
A3	20.5	≈OMC	17.05	105	B3	21.0	≈OMC	16.91	105
A4	20.5	≈OMC	15.39	95	B4	21.0	≈OMC	15.32	95
A5	20.5	≈OMC	14.26	88	B5	21.0	≈OMC	14.19	88
A6	23.5	OMC+2.9	15.39	95	B6	25.0	OMC+3.7	15.32	95

It was assumed that the remolded specimens are representative of compacted material in earth embankments or cores of fill dams. The curing time reflects the time before exposure to flowing water, i.e. first water filling of reservoir. The pinhole test was selected as the main tool for testing erodibility of the tested specimens and was considered suitable for this laboratory study because it is a direct measure of the erodibility of compacted soils, it simulates the flow of water in cracked earth fill, the various grades of its results are useful in checking and comparing the results, its results are reproducible and remolded specimens with varying moisture contents and densities can be tested.

4 PREPARATION AND TESTING OF SPECIMENS

The preparation of specimens was started by screening of the material through a 2 mm size sieve. The material was carefully screened through the sieve and stored inside plastic bags to prevent drying out of the material, after which the moisture content was adjusted to the required moisture content. For preparation of specimens, a special two half-cylinder mould connected with removable clip to allow easy removal of the remolded specimen was manufactured for this study having internal dimensions similar to the pinhole test specimen. Specimens were prepared by filling in the mould in five equal layers with calculated weight of soil for each layer to obtain the specified dry density and moisture content. Each prepared specimen was either immediately pinhole tested or was sealed in plastic bags and stored for the assigned curing period before testing.

Seventy two specimens, 36 for each soil, were prepared in 6 sets of equal moisture content and dry density. Six “identical” specimens from each group were pinhole tested after: No curing (tested immediately after preparation), 6 hours, 1 day, 3 days, 7 days and 1 month.

As a consequence of analysis of the results of the originally planned work, it was deemed useful to prepare some additional specimens with other moisture content and density or to test for more curing times. Another group of specimens was added for Soil B to test moisture content wet of optimum with higher dry density of 101 % of MDD. Also, additional specimens were prepared for groups A2 and A5 of Soil A and for all seven groups of Soil B. These specimens were tested after more than one year of curing.

All specimens were pinhole tested after the planned curing times were attained. At the specified time the test specimen was taken out from the desiccator and the seal was removed. The specimen was then gently entered into the mould of the pinhole test to the required position. After that the test nipple was placed in the specimen to form the hole. After the hole was correctly formed, wire meshes and clean dry pea gravel were placed at the two edges. The two side covers were then fixed to the edges. The mould with the specimen was placed in the pinhole test apparatus and the original testing procedure was followed by causing distilled water to flow through the hole under 50, 180, 380 and 1020 mm heads. The color and turbidity of the out-flow water were observed. The discharge of the out flowing water was determined for every head. The test was stopped whenever the out-flow water was not substantially clear, otherwise it was stopped after 5 min of applying the 1020 mm head. In some cases, when there was no out flow after the 50 mm head was applied, or when the flow was stopped by clogging of the hole after moments of the 50 mm head application, the mould was removed from the apparatus, opened and the hole was reformed before restarting the test again. Usually, this was sufficient to allow continuation of the test. In case of no out-flow the specimen was removed from the mould and a new specimen was prepared to replace the failed one.

All the specimens were identified after the test to one of the grades of the pinhole test: D1 (highly dispersive), D2 (dispersive), ND4 (moderately dispersive), ND3 (slightly dispersive), ND2 (very slightly dispersive) and ND1 (non dispersive).

5 ANALYSIS OF TESTS RESULTS

5.1 *Effect of Moisture Content and Dry Density on Erodibility of Soil A*

5.1.1 *Moisture content wet of optimum*

MC=18.5% (OMC-2.1%): the two higher densities were used for testing this relatively low moisture content. The results for the higher density were found to be always non dispersive regardless of the curing time. The specimens with the other dry density of 15.39 KN/m^3 (95% of MDD), when tested, were found to be dispersive and continued to be dispersive with curing times and only changed to very slightly dispersive to non dispersive after 7 days, 1 month and more than 1.5 year curing times.

5.1.2 *Moisture content at about OMC*

MC=20.5% (approximately = OMC): all the three density levels were tested for this moisture content. For the two higher densities the results were always non dispersive for curing times up to 7 days. The third dry density level (88% of MDD) is the lowest density and may reflect the case of insufficient compaction of material at its OMC, which corresponds to application of less compaction effort. The specimens were dispersive up to 3 days of curing. Only little change occurred after 7 days of curing. After 1 month and more than 1.5 years of curing, the results were found to be very slightly dispersive.

5.1.3 *Moisture content wet of optimum*

MC=23.5% (about OMC+3%): the test was carried out for the dry density of 15.39 KN/m^3 (95% of MDD) only. The results for this combination of moisture content and dry density were always non dispersive irrespective of curing time.

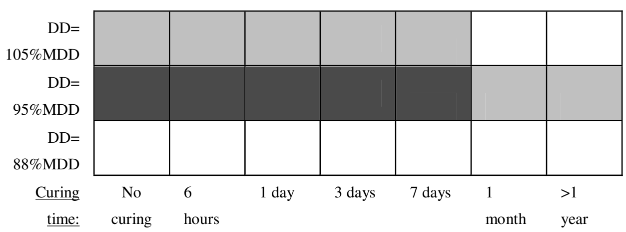
5.2 *Effect of Moisture Content and Dry Density on Erodibility of Soil B*

For this dispersive Soil B material and for such a wide range of moisture content (about 4% above and below OMC), the results were found to be dispersive. Only a negligible or very slight change has been experienced after more than one year of curing for the sample with moisture content of about OMC and the highest tested dry density of 105% of MDD. The material became dispersive instead of highly dispersive, which is not a significant change in the erosion resistance.

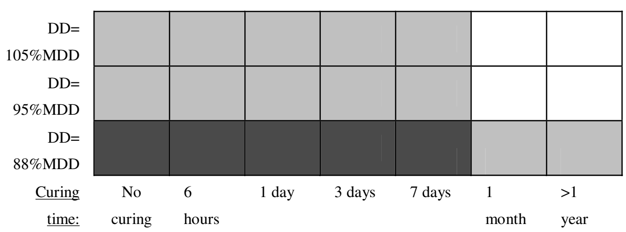
5.3 *Effect of Curing Time on Erodibility of Soil A*

The curing times originally planned for testing all sets of specimens made from Soil A material with different moisture contents and dry densities, were the no curing, 6 hours, 1 day, 3 days, 7 days and 1 month of curing time. From the six sets of specimens, the four ones with the relatively higher moisture contents and dry densities were found to be always non dispersive in the pinhole test. Consequently, they were not tested for the last planned 1 month curing time.

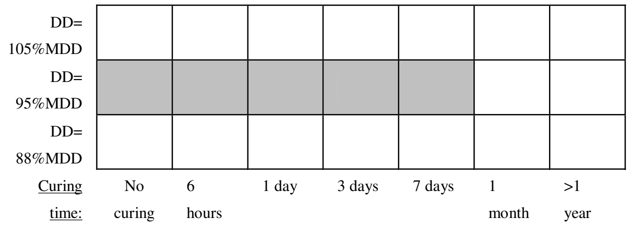
The other 2 sets are the one with the lowest planned moisture content (OMC-2.1) % with 95% of MDD, and the other with the lowest planned dry density, 88% of MDD, compacted with OMC%. For these two sets the results of the pinhole test were more or less dispersive for all the planned curing times except for the last two, 7 days and 1 month. For the specimens with the lowest moisture content and the higher dry density the results were slightly dispersive to non dispersive after 7 days and 1 month of curing and clearly non dispersive for the additional specimen which cured for more than 1.5 year. For the other set of specimens with the lowest dry density and the higher moisture content the results were moderately dispersive after 7 days and slightly dispersive after 1 month as well as after more than 1.5 years. The results of the pinhole test for Soil A specimens are presented schematically in Figure (3).



(a) MC < OMC



(b) MC ≈ OMC



(c) MC > OMC

Figure 3: Pinhole Test Results for Soil A, Moisture Contents: (a) <OMC, (b) ≈OMC and (c) >OMC

It can be concluded that there was an improvement in the erosion resistance of Soil A material with time, and that this improvement was more noticeable for the samples with low bulk density (low moisture content and/or low dry density) since their erodibility was higher before curing in the compacted state.

5.4 *Effect of Curing on Erodibility of Soil B*

All the results of the pinhole testing for Soil B specimens were, with no exception, dispersive for all curing times up to 1 month. In order to see whether some improvement in the erosion resistance could take place after longer curing periods, additional specimens were prepared with all the planned moisture contents and dry densities. After more than one year of curing these specimens were pinhole tested and the results were still dispersive as they were before, except that a minor change in the result for the specimen prepared at the highest dry density using the OMC was exhibited. This change was from highly dispersive to dispersive, which could be considered as a negligible change with no real significance in the erosion resistance behavior. However, it may indicate that more improvement can be expected for very longer curing periods especially if cured under loaded condition.

6 CONCLUSIONS

This paper presents the results of a laboratory investigation for dispersivity and erosion resistance of two River Nile deposits, Soil A and Soil B, with regard to compaction moisture content, density and curing time after compaction. Physical and chemical tests have shown that Soil A is slightly dispersive while Soil B is highly dispersive.

The slightly dispersive Soil A has shown noticeable trend of less erodibility for high densities and moisture contents. The specimens with the lowest moisture contents and dry densities were less erosion resistant, and have shown improvement towards better erosion resistance with curing time after compaction. Slightly erosive/dispersive soils could therefore resist erosion better if well compacted with moisture content wet of the Optimum Moisture Content and are allowed after compaction to stay for sometime before exposure to eroding water.

The highly erosive Soil B material did not show improvement for high dry densities and moisture content and was very slightly affected by curing after more than one year, showing negligible change from highly dispersive to dispersive. This is not a considerable change in the erosion resistance behavior, but is probably an indication of improved behavior after relatively longer curing times.

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