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Use of Milk of Lime for Dispersive Soil Treatment in the Region of Tlemcen in Algeria

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***Abstract*— Water infiltration into the ground can change its characteristics when small particles are picked up and hence its porosity (permeability) changes. This phenomenon is well known in the literature as the internal erosion. This problem is quite important in regions of water storage where the interstitial pressures are very important. However, the erosion process is highly dependent on soil susceptibility to dispersion.**

According to the International Commission On Large Dams (ICOLD), dams can be built with dispersive clay if certain precautions are taken (Fell, 1992). Several solutions have been suggested in order to lower the soil sensitivity to dispersion, or even prevent the internal erosion by the use of lime, fly ash.... This technique is effective but can only be used for new constructions, as it requires a qualified workforce for its implementation.

In this paper, some experimental results on the effect of addition of milk of lime to dispersive soils are reported. This can easily be carried out in practice and responds positively and equally for both new and old constructions. The treatment results are shown using classical erosion tests: crumble test, pinhole test and double hydrometer test. This study clearly shows that adding a small percentage of milk of lime slightly increases the soil strength and significantly reduces its dispersion. The authors provide a practical explanation of this technique about the decrease of the dispersive nature of clays.

***Keyword*— Dispersion, Erosion, Treatment, Milk of lime, Crumble test, Pinhole test**

I. INTRODUCTION

Since the birth of geotechnical engineering, land use has become very important in the field of civil engineering, specifically in the road sector and more particularly in dam construction, where the actual percentage of embankment dams is more than 60% (Figure 1). This increase in land use is the consequence of the good understanding of soil mechanics principles and the economic use of natural materials.

This increase was accompanied by a large number of problems resulting from major human and economic disasters: Vajont dam (Italy, 1963), destroyed by a landslide, where about 1994 people died (Rouissat, 2002), Titondam (United States, 1976) destroyed by internal erosion, where14 people and 13,000 head of cattle perished. The damage estimation is around 400 million dollars (U.S. Department of Interior1976).

Foster et al. (2000) conducted a statistical study on 11,192 hydraulic structures in the ground; 136 underwent disorders with 6% by landslide, 46% by internal erosion and 48% by overflow (Rosquoët, 2005). Thus, the risk of a dam failure by internal erosion increases with its age. Therefore this mechanism is greatly responsible for the instabilities observed on site and has become a major concern for hydraulic structure specialists.

The presence of dispersive soils poses a risk to the stability of the structure. Before,these soils were not used for embankment constructions, and this made work more difficult and expensive, but nowadays dispersive soils are used in constructions after chemical treatment.

The region of Tlemcen in Algeria is well known for its rich water sources. Indeed, there are six dams: an arch dam, a mixed dam and four embankment dams. Figure 2 shows the geographical location of these pieces of work. Another embankment dam is under study in the region of Beni-Ouarsous. Preliminary studies have clearly shown the dispersive nature of soils which cannot be used in the realization of dam clay cores. Dispersive soils were treated in the laboratory in order to improve their dispersion characteristics and increase their shear strength. The milk of lime was chosen as an additive in this study. The results show that there is an optimum content of milk of lime that gives a treated soil more resistant to dispersion. This article aims to provide details for this methodology, as this protocol is very useful in engineering practice.

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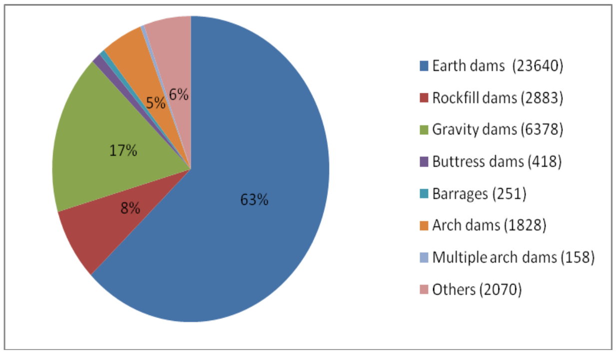

Figure 1: Proportions for dam types (Icold, 2012).

II. OVERVIEW OF DISPERSIVE SOILS

Dispersive soils are characterized by an unstable structure, easily flocculated in water, and very erodible (Zorlueret al., 2010). These soils are highly erodible in nature and tend to crumble in the presence of water and erode under low flow rate, which leads to stability problems in earthworks. Erosion due to soil dispersion depends on the mineralogy and chemical composition of clay as well as on the salts dissolved in interstitial water. Soil dispersivity is mainly due to the presence of exchangeable sodium present in the composition of clays, in which the attractive forces are weaker than the repulsive ones. This enables the particle to separate and move freely.

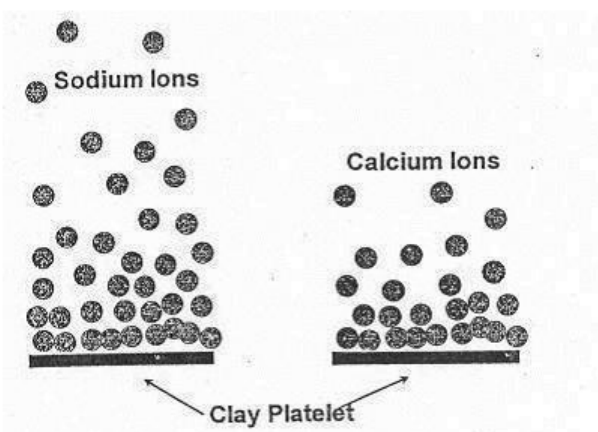

Figure 2: Behavior of sodium and calcium ions attached to a clay platelet. (Source: Hanson et al., 1999)

III. SITE LOCATION AND IDENTIFICATION OF THE STUDIED SOIL

The experimental study was performed on reworked clay which comes from the region of Beni-Ouarsous, in the north of the wilaya (province) of Tlemcen in Algeria.

The sampling was taken at a depth of 2 meters, using a hydraulic excavator.

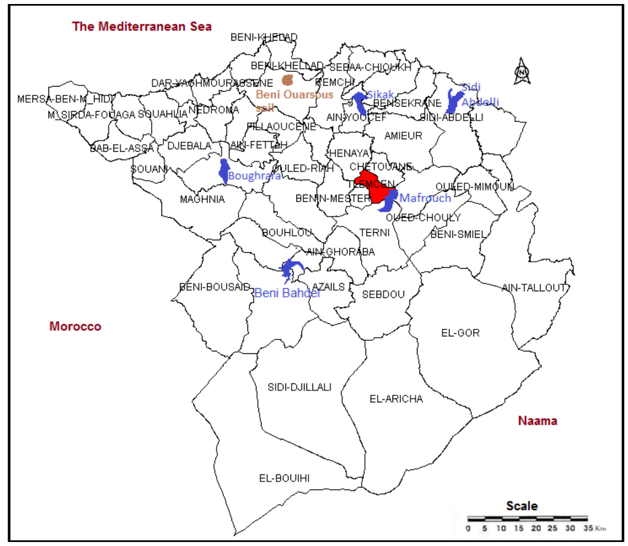

Figure 3: Location of Tlemcen dams and sampling site

Mechanical and physico-chemical identification tests were performed in the Geotechnical Laboratory of the Faculty of Technology, University of Tlemcen. The results are summarized in Table 1.They show that soil is highly plastic clay, non-marly and inorganic, as classified by LCPC.

TABLE I
GEOTECHNICAL PROPERTIES OF BENI OUARSOUS SOIL

Physical identification	Value	Standard
Particle size		XFP 94-056
Gravel (%)	0,5	NFP 94-057
Sand (%)	17,5	
Silt (%)	15	
Clay (%)	67	
Finer content (< 80 µm) (%)	92,5	
Atterberg limits		NFP 94-051
Liquid limite (%)	78,1	
Plastic Limit (%)	30,56	
Plasticity index (%)	47,54	
Specific gravity	2,72	NFP 94-054
Chemical identification		
Blue value	12,37	NFP 94-068
Specific surface (m2/g)	259,81	
CaCo3 (%)	3,18	NFP 94-048
Organic matter (%)	1,02	NFP 94-055
Mechanical identification		
Proctor normal		NFP 94-093
Maximum dry density (kN/m^3)	15,90	
Optimum moisture content (%)	21,9	

IV. Milk Of Lime Property

Milk of lime is a saturated solution of calcium hydroxide (Ca (OH) 2), a mixture of hydrated lime and water. Its characteristics are summarized in Table 2.

Table 2
Chemical composition of milk of lime

Component	Percentage (%)
Ca(OH)2	7,5 to 8
NaOH + KOH	0,2 to 0,6
H2O	91 to 92

V. Results And Discussion

A. Milk of lime effects on physical parameters

1. The Optimum Proctor

The Proctor test consists in moistening the soil at various water contents for every milk of lime dosage and compacting according to the standard procedure of the test. For each water content value, the density of dry soil is determined and the curve of the variation of this density as a function of water content is drawn. The curve shows a maximum value of the dry density which corresponds to a particular *water content value*. The curves shown in Figures 4 and 5 give the variation of dry density as a function of water content for different contents of lime milk.

The use of lime of milk leads to an increase in the optimum moisture content and a decrease in the dry density at first. However, beyond a threshold value of 6% in this case, the opposite happens. This agrees with the description of the compaction phenomenon as the milk of lime increases the lubrication between solid particles.

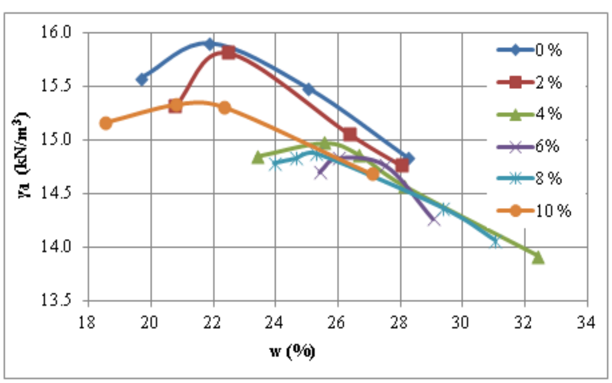

Figure 4: Milk of lime effect on the Proctor curve

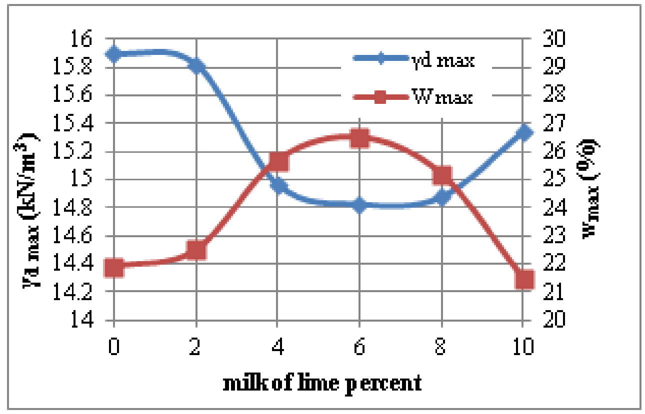

Figure 5: Milk of lime effect on the optimum Proctor

2. Atterberg limits

Atterberg limits are conventional measures expressing differences in the mechanical behavior of soils. These differences are mainly attributed to changes in water content. Normally, they correspond to the thresholds of transition from solid to plastic, and then from plastic to liquid.

The addition of milk of lime has a significant influence on the Atterberg limits. It is clear that an increase in milk of lime content causes a substantial increase in the Atterberg limits. This increase is larger for the plasticity limit than for the liquidity limit. However the plasticity index reaches a maximum value (4%) and then gradually decreases for large contents of milk of lime.

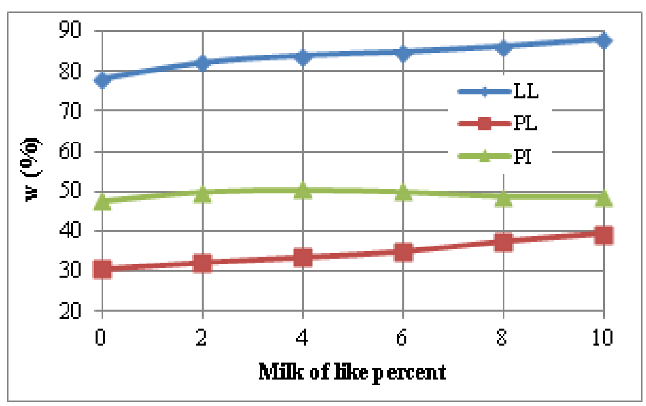

Figure 6: Milk of lime effect on Atterberg limits

3. Void ratio

In order to measure the void ratio of a sample, it is necessary to determine its volume.

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This is carried out by hydrostatic weighing in non-wetting oil which is the Kerdane (kerosene). The void ratio will then be deducted from the following formula:

$$e = \frac{\gamma_s}{\gamma_d} - 1$$

Where :

γ_s : Specific gravity of solid grains

γ_d : Dry density

The measurements were performed on samples prepared at different percentages of milk of lime and the results are shown in Figure 7.

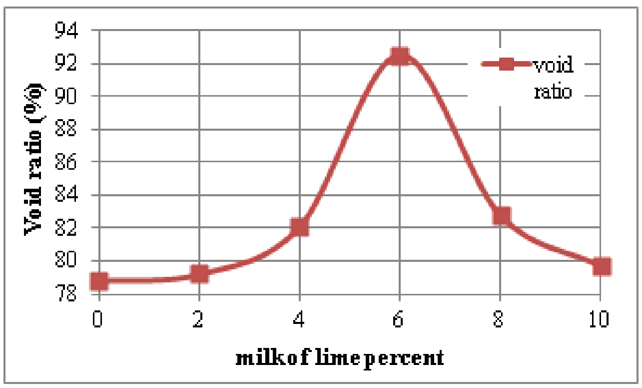

Figure 7: Milk of lime effect on void ratio

Figure 7 shows that soil in its natural state (dispersive) is characterized by a low void ratio, and the addition of milk of lime gradually increases its void ratio as a result of the flocculation of small particles, and this gives grains of larger size, hence a larger void ratio. The influence of the additive reaches its maximum value for a percentage of 6%, beyond which the reverse effect occurs and this corresponds to a low void ratio.

B. Milk of lime effects on on dispersion tests

1. Crumb test

This test is the simplest way for the identification of dispersive soils. It is solely based on direct qualitative observations. This test consists in preparing cubic samples of soil (side length about 15 mm) which are then immersed in distilled water (250ml). The sample must be placed on the bottom of a glass cylinder, near the edge. The soil particles tend to disperse in a colloidal suspension, and this can be seen in the cloud that forms after 2 minutes, 1 hour and 6 hours. Depending on the degree of turbidity of the cloud, the soil is classified in one of four levels of dispersion, in accordance with ASTMD6572-00.

Some samples were prepared in the laboratory at different percentages of milk of lime and at the maximum density, as shown in Figure 1, and then tested by the crumble test. The results are summarized in Table 3.

TABLE 3
EFFECT OF MILK OF LIME ON THE CRUMB TEST

% milk of lime	After 2 min		After 1 hour		After 6 hour	
	Sample tested	Dispersion class	Sample tested	Dispersion class	Sample tested	Dispersion class
0	1	D1	2	D3	2	D3
	3	D2	2	D4	2	D4
2	4	D1	3	D2	3	D2
	/	/	1	D3	1	D3
4	4	D1	2	D1	2	D2
			2	D2	2	D2
6	4	D1	4	D1	3	D1
	/	/	/	/	1	D2
8	4	D1	3	D1	2	D1
			1	D2	2	D2
10	3	D1	3	D2	2	D2
	1	D2	1	D3	2	D3

Once again, the results show that the soil reaches its maximum strength for a 6 % content of milk of lime and becomes non-dispersive. However, beyond this value the reserve effect occurs, and consequently the soil loses its strength with respect to dispersion. This explains once more the effect of this treatment.

2. Double hydrometer test

Clay granulometry is performed according to the ASTM procedure in two ways (Tarog, 2000). The first one is carried out using a standard test where the clay sample is dispersed using a chemical agent (sodium hexametaphosphate) and by mechanical agitation. The second manner follows the same procedure but without the dispersive agent and the mechanical agitation. From the two granulometries recorded, it comes out that clay tends to have a natural dispersion.

The double hydrometer test allows to establish the dispersion ratio D defined as the ratio of the percentages of tiny particles less than 5 microns, in the two specific test cases:

$$D = \frac{\%\ \text{finer} < 5\,\mu\text{m}\ (\text{No dispersant})}{\%\ \text{finer} < 5\,\mu\text{m}\ (\text{Standard})} \times 100$$

If D is close to 100%, the soil is completely dispersive. However, if D is very small (near zero), it is totally non-dispersive. Figure7 summarizes the results of this study.

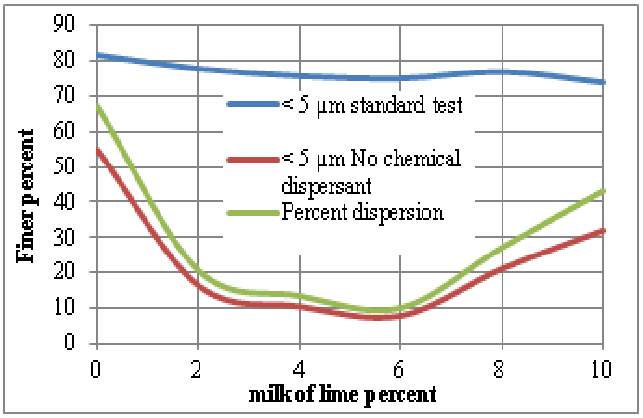

Figure 1: Percent dispersion as determined from the double hydrometer test

The lime effect is seen in the results mentioned above. It was found that a very significant melioration is noted with a 6% addition. The soil changes from class D4 dispersive (D = 67.08) to class D1non-dispersive (D = 10.11).

Nevertheless, it was noticed that after this dosage, and only for the studied soil, dispersibility can be obtained if the milk of lime content increases.

3. Pinhole test:

In this test, water flows through a *hole* with a diameter equal to 1 *mm*, formed in a 38 mm high cylindrical soil sample.

In the initial phase, water flows under a 50 mm hydraulic load. For resistant clays, water comes out perfectly clear, and then the load must be increased in steps to180 mm, then and 380 mm, 1020 mm. Each step is maintained for 5 min. Erosion of dispersive soils occurs under the first load. The analysis and interpretation are based on the flow rate, the color of the water collected and the final diameter of the hole. Various observations are used to classify the sample in terms of dispersion into six classes defined by ASTM (D 4647-06).

Some samples were prepared in the laboratory at different percentages of lime of milk and at the maximum density, and then tested by the Pinhole test. The results are summarized in Table 4.

TABLE 4
EFFECT OF MILK OF LIME ON THE PINHOLE TEST

Milk of lime Percentage	Sample tested	Dispersion class
0	3	D2
	2	ND4
2	4	ND3
	1	ND2
4	1	ND3
	4	ND2
6	5	ND2
8	5	ND2
10	5	ND2

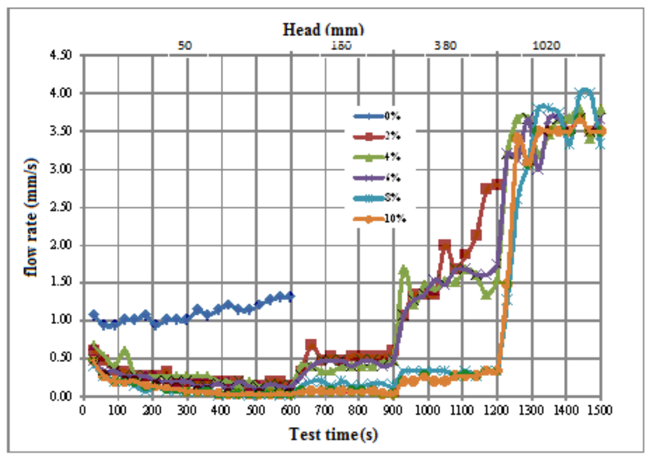

Figure 9: Flow rate vs time in the pinhole test

Figure 9 shows the variation curves of the flow rate during the pinhole test for the samples prepared at different lime of milk contents. Natural soil is a dispersive soil of Class D2. A higher flow rate is observed in the last phase (10 minutes); and the flow rate is greater than 1 mm / s under a 5 cm load. The addition of lime milk increases the shear strength of the hole caused by water circulation and gives a stable flow rate. As the additive content goes beyond 4%, the soil becomes non-dispersive of class ND2. At the beginning of the test, the flow rate decreases and the hole is obstructed because of soil swelling inside it. However, at the beginning of the test, when the additive content is equal to 8%, the soil reaches a better strength, which corresponds to a low hydraulic load (up to 38 cm).

However, as soon as the load increases (102 cm), erosion starts suddenly, and the hole diameter becomes very large in seconds (> 3 mm).

VI. CONCLUSION

Stabilization by addition of milk of lime has some positive effects on all the characteristics of the dispersive soil used in this study. Indeed, the results showed that the addition of milk of lime improves the soil properties and increases its resistance to erosion. In fact, the addition of milk of lime reduces the value of the maximum density and the optimum position moves towards larger water contents. The maximum effect is reached for an additive content of 6%, and then the reverse phenomenon occurs.

The percentage of 6% of milk of lime is a dosage of great importance, as it represents the optimal threshold value with a positive effect on the dispersive nature of soil:

1 - The transition from highly dispersive to non-dispersive for the soil under study was found at a threshold of 6% after which the soil returns to its initial dispersive state as show the crumb test.

.2 - The most predominant effect on the dispersion index during the double hydrometer test was recorded once again at 6%. This index went from 67% to 10%.This fact confirmed the importance of adding a specific percentage in order to improve the properties of soil, particularly to decrease its dispersion.

3 - The passage from a dispersive soil of class D2 according to the pinhole test to a non-dispersive soil of class ND2, starting from a dosage of 4%

According to the pinhole test, when soil is treated at a dosage greater than 6%, it becomes highly resistant to soil erosion, but only for small hydraulic loads and then it suddenly loses its strength at higher loads (102 cm of the test). In practice, this means that the use of a dosage greater than 6% can be risky, as a sudden breach can form in the dike and may be very dangerous for the safety of the structure. Henceforth, a dosage of 5% of milk of lime is suggested.

The ongoing researches on other soils will soon prove if this is an intrinsic value or rather a characteristic of a state.

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