Soil Stabilization in the 9th District of N'Djamena, Chad, Through the Addition of Lime or Cement for the Construction of Hydraulic Structures

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Abstract — The frequent failure of earthen hydraulic structures necessitates knowledge of the soil from the quarry used and the improvement of its geotechnical and mechanical characteristics to ensure their durability. The objective of this study is the stabilization of the soils in the 9th district of the city of N'Djamena in Chad, used particularly for the construction of protective dikes, through the addition of lime or cement. A sample taken, deemed unsuitable for the construction of hydraulic structures, is subjected to identification tests (particle size analysis, Atterberg limits, and bearing capacity). Stabilizing the sample with lime and cement resulted in an increase in fine particles from 50.4 to 70.5 and from 50.4 to 68.3, respectively; a decrease in the plasticity index from 22.3 to 17 with lime and from 22.3 to 16 with cement. A significant improvement in soil bearing capacity was also observed, from 10 to 20 at 98% of the Modified Proctor Optimum (MPO), and from 10 to 36 at 98% of the MPO, respectively, for lime and cement. The addition of lime or cement also results in a decrease in dry unit weight from 1.81 to 1.65 kN/m³ with lime and from 1.81 to 1.70 kN/m³ with cement, and an increase in water content at the absolute minimum pressure (OMP) from 16% to 17.6% and from 16% to 37.4%, respectively. Modifying these parameters with lime or cement improves the geotechnical and mechanical characteristics of the soil, providing optimal performance and making it suitable for the construction of hydraulic structures.

Keywords: Stabilization, Soil, Lime, Cement, Hydraulic Structures

I. Introduction

Rapid population growth and the high cost of land acquisition force people to build in potentially flood-prone areas. Water containment structures such as dikes and dams represent a very expensive investment. Their construction uses earth as a base, which makes them prone to failure if sufficient studies are not conducted. However, constructing hydraulic structures from earth is an economical solution for reducing flood risks. More than 70% of hydraulic structures worldwide are made of earth, thus regularly exposing populations to the risk of failure. In Chad, hydraulic structures are built using earth extracted from various sources without prior studies to determine their characteristics and ensure the structures' performance. To ensure the sustainable development of civil engineering structures, knowledge of soil characteristics determines the main economic and environmental challenges in order to encourage the use of local materials. The use of treatment products remains an economical and innovative option for utilizing materials with poor geotechnical and mechanical properties found on local sites. One solution for soil treatment is the use of lime or cement, which modifies the mechanical behavior and workability of the soil to make it suitable for various uses.

Our study focuses on the soil stabilization of the 9th arrondissement of N'Djamena, Chad, through the addition of lime or cement for the construction of hydraulic structures. The stabilization techniques tested in this work involve stabilizing a sample, designated DO2 [1], deemed less suitable for the construction of hydraulic structures, which was treated with lime or cement.

II. Study Methodology

Two commonly used soil treatment products were selected: lime and cement. The lime used was quicklime type CL 90 (CARMEUSE), while the cement was Portland cement, reference CPJ 42.5 from CIMAF Chad, with a true strength of 45 MPa. Its main constituents are clinker (65 to 79%), as well as limestone and fly ash. The lime and cement were packaged in plastic bags of a few hundred grams, hermetically sealed until use. The soil samples were treated with 1% and 3% lime and with 3% and 6% cement. The dosages used conform to the standard dosage and correspond to the maximum commonly used in earthworks [2]. Tab. 1 shows the different percentages of treatments applied.

Nature of treatment	Dosage	
Lime	1%	3%
Cement	3%	6%

Table 1: Soil treatment method.

Particle size analysis is obtained by dry sieving after washing according to standard NF P 94-056 [3]. Atterberg limits are determined according to standard NF P 94-051 [4]: the liquid limit WL by cupping and the plastic limit WP by rolling. Classification is carried out according to standard NFP11-300 [5]. Bearing capacity is evaluated by Proctor and CBR tests in accordance with standards NF P 94-093 [6] and NF P 94-078 [7].

III. Results and Discussion

A. Lime Treatment

1) Particle Size Distribution

The particle size distribution curves established, before and after treatment with lime, are shown in Fig.1 and Tab.2, which allow us to understand the influence of the treatment on the soil.

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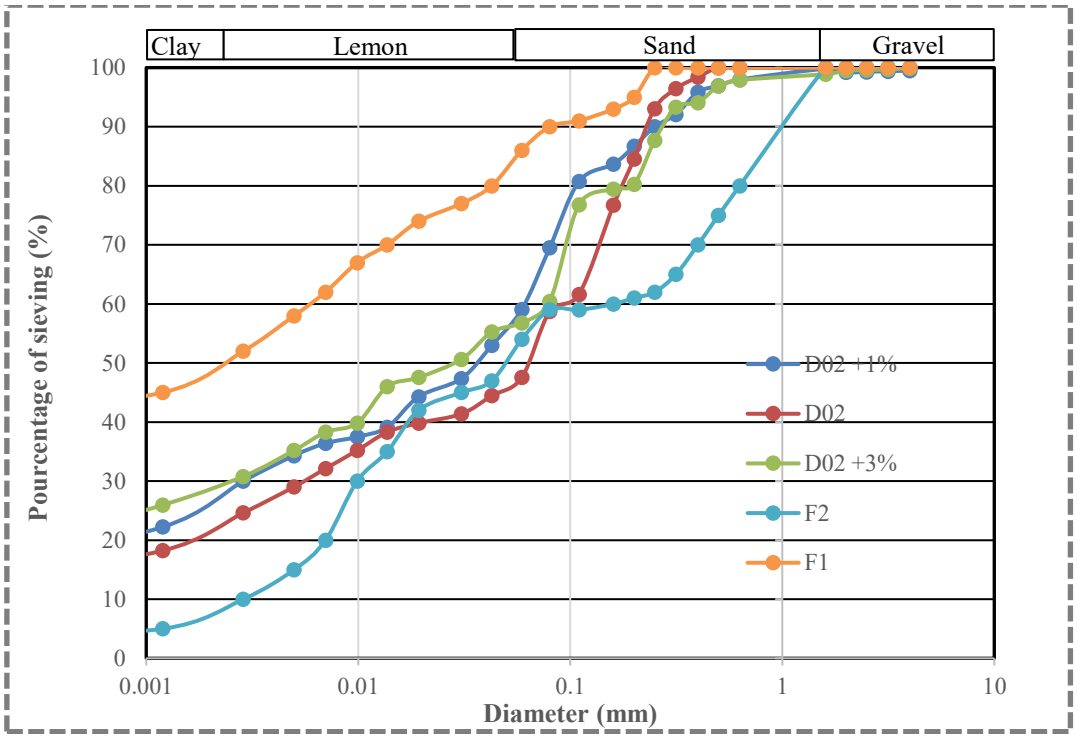


Fig. 1: Particle size distribution curves before and after treatment with 1% and 3% lime

Samples	Diameter				
	< 0,08mm	< 0,2mm	< 0,5mm	< 2mm	< 4mm
	Sieve loops (%)				
D02 + 0% lime	54.4	80.1	98.7	100	100
D02 + 1% lime	69.5	86.5	96.9	99.7	100
D02 + 3% lime	60.4	80.2	96.8	99.5	100

Table 2: Particle size distribution of the sample treated with 1% and 3% lime.

Adding lime to the soil increases the percentage of fine particles. One of the main consequences of soil treatment with cement or lime is particle agglomeration, which contributes to the increase in the percentage of fine particles [8]. This agglomeration phenomenon is due to cation exchange reactions between clay particles and Ca2+ ions resulting from the reaction between quicklime (CaO) and water molecules (H2O). Pozzolanic reactions are also responsible for particle agglomeration.

2) Atterberg Limits

The results of the Atterberg limit tests on the soil sample taken before and after lime treatment are presented in Tab.3, and the curve in Fig.2 shows the evolution of the Atterberg limit for the sample as a function of the lime percentage.

Samples	WL	WP	IP
Untreated soil	50.6	28.3	22.3
Soil treated with 1%	51	31	20
Soil treated with 3%	59	42	17

Table 3: Atterberg limits on the soil sample taken before and after lime treatment.

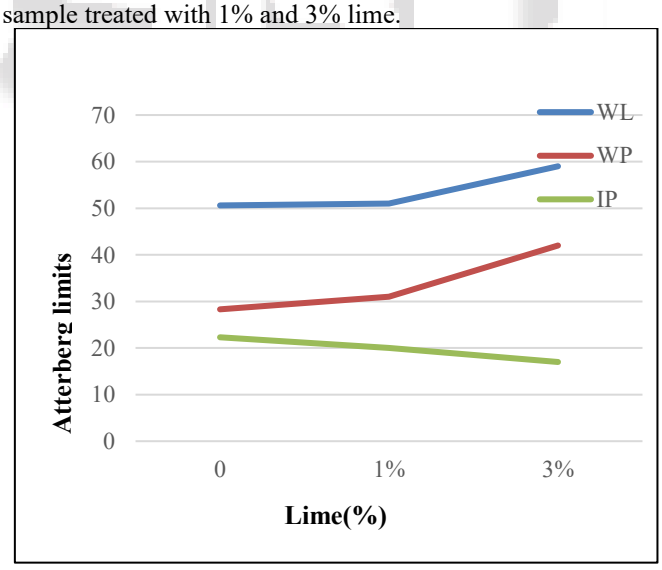


Fig. 2: Influence of lime on Atterberg limits.

We observe an increase in the plasticity limit and a change in the liquid limit. The plasticity index drops from 22.3 before treatment to 17 after treatment with 3% lime. This implies a decrease in water sensitivity. Fig.3 presents the histogram of the variation of the plasticity index as a function of the lime content.

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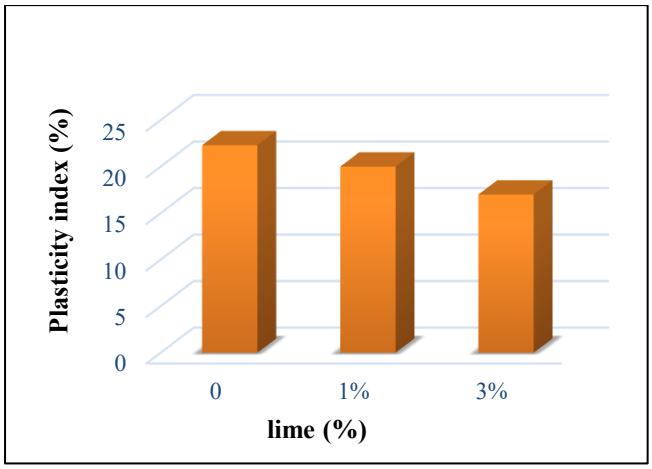


Fig. 3: Histogram of the plasticity index as a function of lime content.

The cation exchanges that occur between the surface of the clay sheets and free Ca2+ ions after hydration are partly responsible for the decrease in these parameters. This exchange leads to the flocculation-agglomeration of the clay particles and then to a reduction in the plasticity of the clay fractions [8]. These results are consistent with those obtained by several researchers, notably Ola in (1977) [9], Bozbey and Garaisayev in (2010) [10], and Issakou MS in (2016) [11].

3) Bearing Capacity

The results of the Proctor and CBR tests before and after treatment of the sample are given in Tab.4. These tests initially determined the dry unit weight and the water content (OPM), and then the CBR indices at 90%, 95%, and 98%.

	Y_{OPM} (KN/m^3)	W_{OPM} (%)	CBR90	CBR95	CBR98
Untreated soil	1.81	17.8	1	5	10
Soil treated with 1%	1.71	18.1	3	6	15
Soil treated with 3%	1.65	20.6	5	9	20

Table 4: Proctor and CBR tests before and after treatment of the sample taken with lime.

The results of the compaction tests under Modified Proctor conditions are shown in Fig.4. These curves show the variation of dry density as a function of water content WOPM(%).

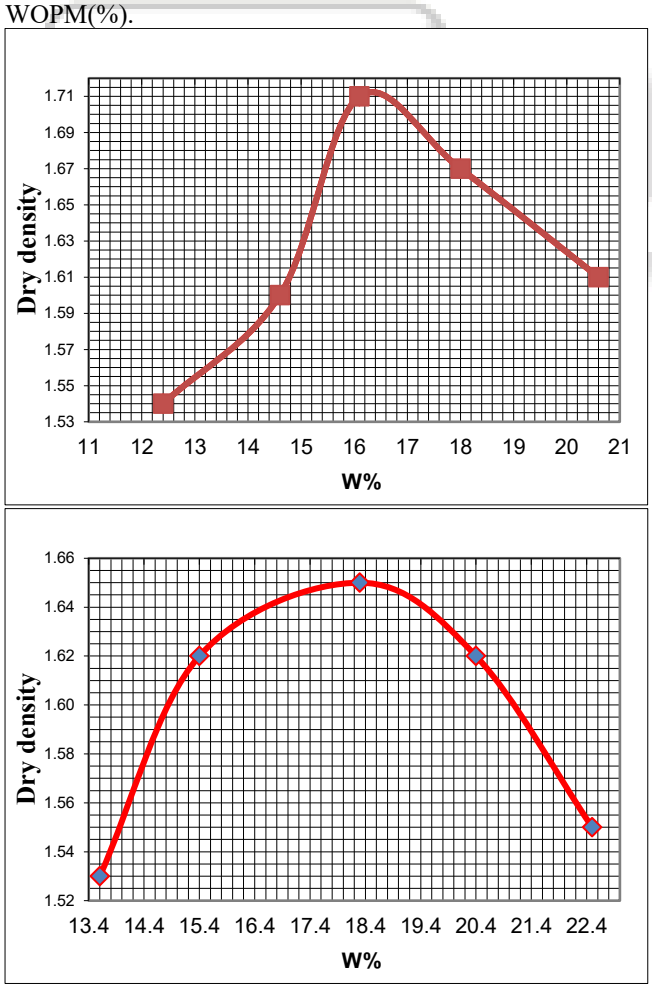


Fig. 4: Proctor curves of the sample treated with 1% and 3% lime.

These tests show a decrease in dry unit weight from 1.81 to 1.65 kN/m³ and an increase in water content from 16 to 17.6. The bearing capacity increased considerably: from 1 to 5 at 90% OPM, from 5 to 9 at 95% OPM, and from 10 to 20 at 98% OPM. Fig. 5 shows the CBR curves of the D02 sample after the addition of 1% and 3% lime.

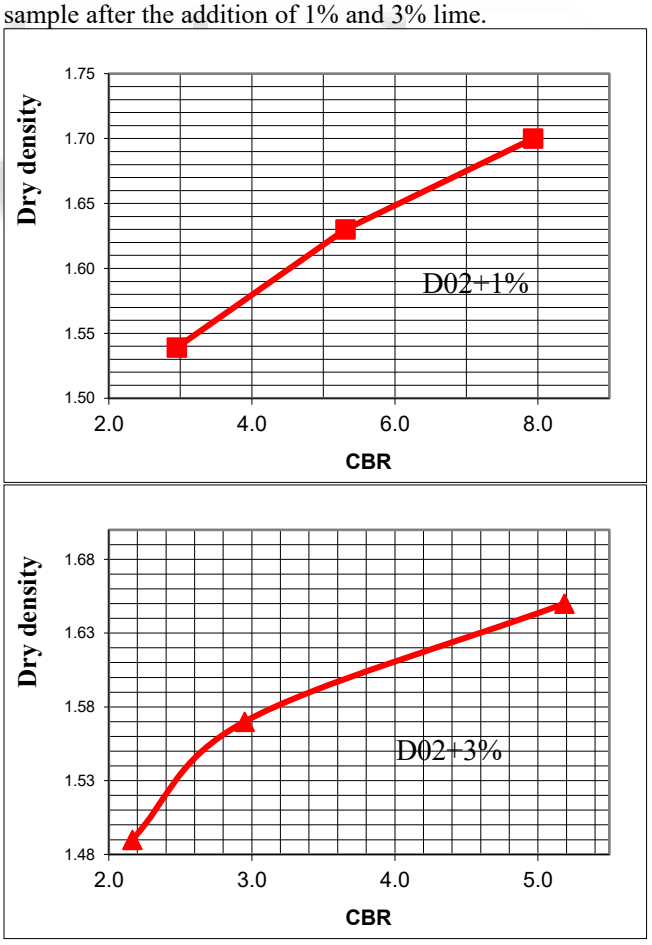


Fig. 5: CBR curve of the sample treated with 1% and 3% lime.

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B. Cement Treatment

1) Particle Size Distribution

The particle size distribution of the sample taken after mixing with 3% and 6% cement is shown in Fig.6, and Tab.5 gives the percentage values of particles passing through the sieves. A change in particle size distribution is observed. The fine particles have increased.

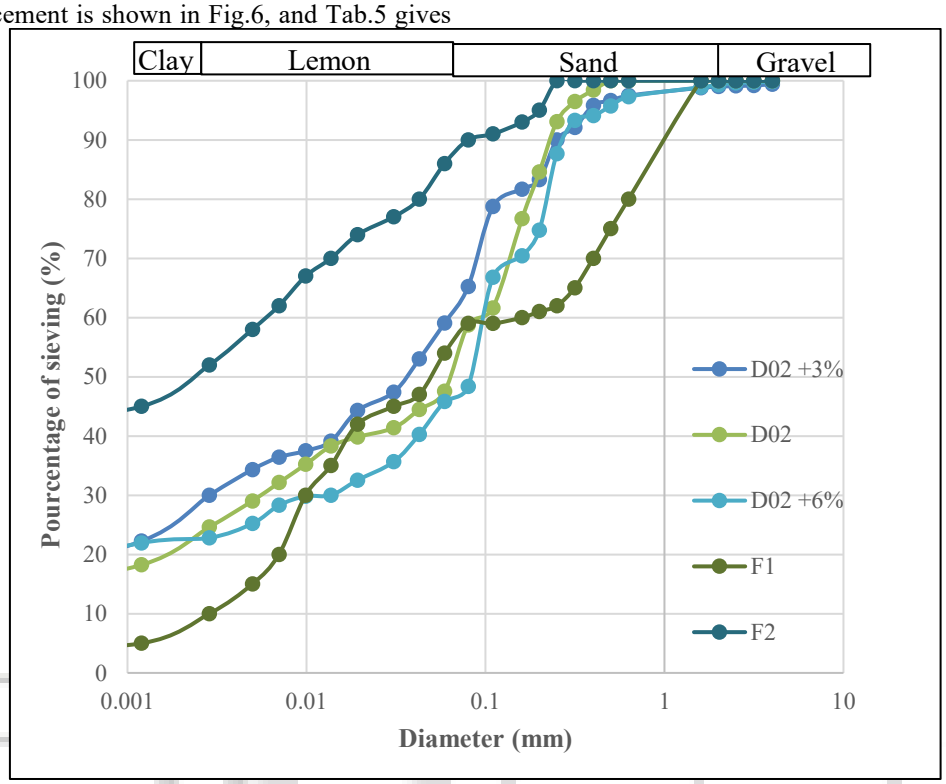


Fig. 6: Particle size distribution curves before and after treatment with 3% and 6% cement.

Samples	Diameter				
	< 80µm	< 0.2mm	< 0.5mm	< 2mm	< 4mm
	Sieve loops				
D02 + 0% cement	54.4	80.1	98.7	100	100
D02 + 3% cement	65.2	83.2	96.6	99.6	100
D02 + 6% cement	48.3	74.7	95.6	99.3	100

Table 5: Particle size distribution of the sample treated with 3% and 6% cement.

2) Atterberg Limits

For the samples stabilized with 3% and 6% cement, the Atterberg limit values are summarized in Tab.6, and the curves in Fig.7 show the influence of cement on the Atterberg limits. The liquid and plastic limits increase with the addition of cement. The plasticity index decreases from 22.3 to 16. Fig.8 presents the histogram of the variation of the plasticity index as a function of cement content.

Samples	WL	WP	IP
Untreated soil	50.6	28.3	22.3
Soil treated with 3%	50.9	29	21.9
Soil treated with 6%	55	39	16

Table 6: Results of Atterberg limit tests on the soil sample taken before and after treatment with 3% and 6% cement.

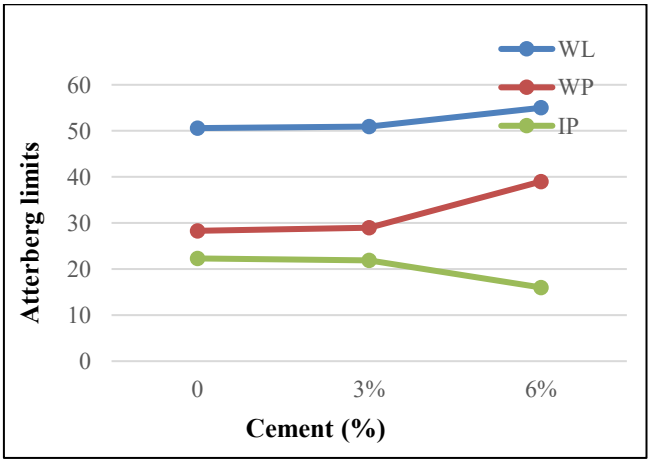


Fig. 7: Influence of cement on Atterberg limits

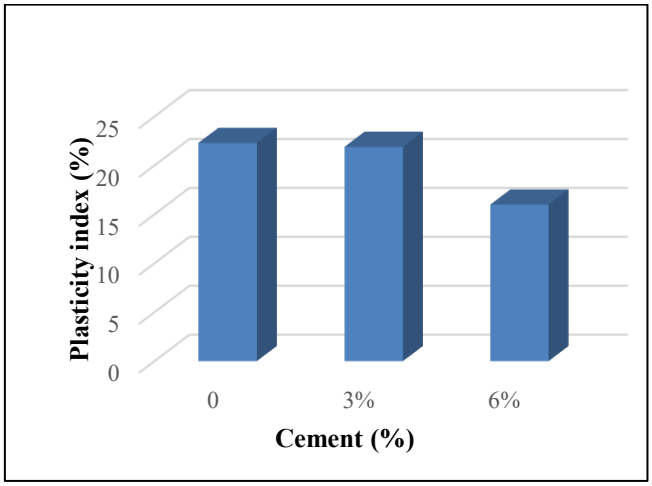


Fig. 8: Histogram of the variation of the plasticity index as a function of cement content

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3) Proctor and CBR.

The results of the Proctor and CBR tests before and after treatment of the sample with cement are summarized in Tab.7. The observed variations are similar to those observed with lime. A decrease in dry bulk density and an increase in water content is observed. Fig. 9 shows the curve of the variation of dry density as a function of water content.

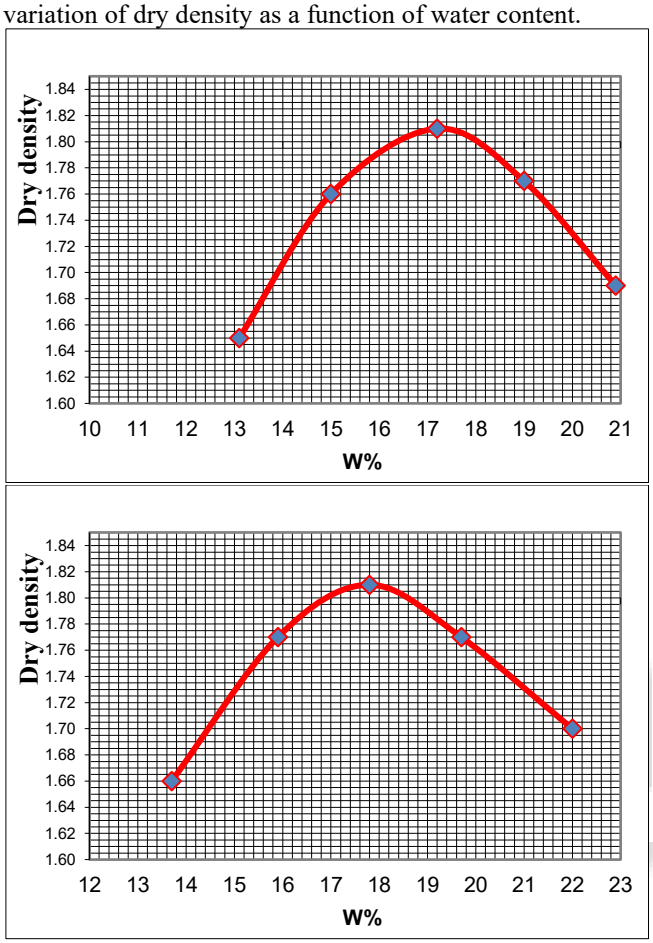


Fig. 9: Proctor curves of the sample treated with 3% and 6% cement.

An increase in bearing capacity is observed from 1 to 26 at 90% OPM, from 5 to 33 at 95% OPM, and from 10 to 36 at 98% OPM. Fig. 10 shows the CBR curves of the D02 sample after the addition of 3% and 6% cement.

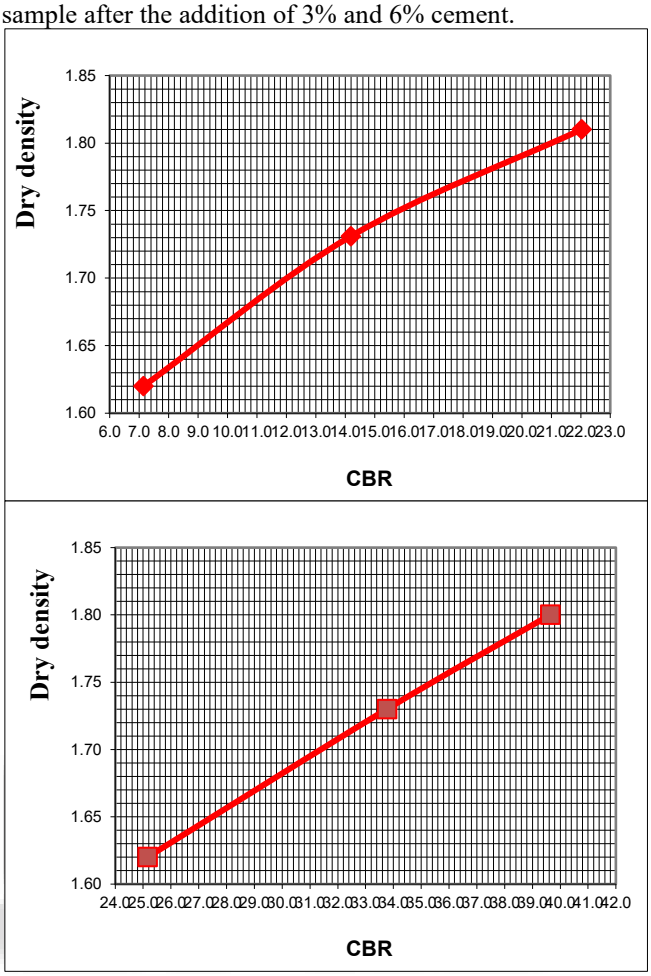


Fig. 10: CBR curve of the sample treated with 3% and 6% cement.

Samples	Y_{OPM} (KN/m$^{3)}$	W_{OPM} (%)	CBR90	CBR95	CBR98
Untreated soil	1.81	17.8	1	5	10
Soil treated with 3%	1.81	16.8	7	13	18
Soil treated with 6%	1.84	17.4	26	33	36

Tab. 7: Results of the Proctor and CBR tests before and after treatment of the sample taken with 3% and 6% cement.

The behavior observed in this sample is also noted by various researchers who have studied this question, including Ola in (1977) [9], Bozbey and Garaisayev in (2010) [10], and Issakou MS in (2016) [11]. It should be noted that the load-bearing capacity improved significantly with cement compared to lime.

IV. Conclusion

Soils used for the construction of hydraulic structures sometimes have poor geotechnical and mechanical characteristics, making them unsuitable for use. These types of soils were found on the flood protection dike in the 9th Arrondissement of N'Djamena. The objective of our work is to improve these geotechnical and mechanical characteristics by adding lime and cement, thereby making them usable. Stabilizing the sample with lime or cement greatly improved the soil bearing capacity according to the Modified Proctor Optimum (MPO) values (from 1 to 5 at 90% MPO, from 5 to 9 at 95% MPO and from 10 to 20 at 98% MPO with lime and from 1 to 26 at 90% MPO, from 5 to 33 at 95% MPO and from 10 to 36 at 98% MPO with cement). The addition of these products also results in a decrease in dry bulk density (from 1.81 to 1.65 kN/m³ with lime and from 1.81 to 1.70 kN/m³ with cement) and an increase in water content at the absolute minimum moisture content (from 16% to 17.6% with lime and from 16% to 37.4% with cement), a decrease in the plasticity index (from 22.3 to 17 with lime and from 22.3 to 16 with cement), and an increase in fine particles (from 50.4 to 70.5 with lime and from 50.4 to 68.3 with cement). Modifying these parameters improves the geotechnical and mechanical characteristics of the soil and makes it suitable for the construction of hydraulic structures, particularly dikes and dams. However, the best performance

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is observed with cement than with lime, although they are close.

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