Influence of the Incorporation of Alluvial Sand on the Mechanical Behavior of Marl Soil

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ABSTRACT

This study aims to evaluate the mechanical behavior of marl soil by replacing it with alluvial sand at 3, 5, and 10% by weight for a possible application in road geotechnics. After a geotechnical characterization of the materials used, the mixtures were characterized by the Atterberg limits test, the soil compressibility test, and the shear strength test. The results obtained showed that replacing a part of marl soil with alluvial sand had a positive impact on its mechanical behavior, as it improved cohesion and shear strength while significantly reducing compressibility and plasticity. These results confirm the possibility of using alluvial sand as a fine soil reinforcement or stabilization material.

Keywords-marl soil; alluvial sand; mechanical behavior; improvement

I. INTRODUCTION

Soils are universally found in nature and used in many areas of human activity, particularly in geotechnical engineering. Soils play a supporting role for various structures in civil engineering or public works and are also the basic elements of a wide range of geotechnical constructions. Fine soils contain notable proportions of clays and silts that influence their intrinsic geotechnical properties. These soils deform under applied loads with amplitudes that can go from a few millimeters to a few meters. They also swell and become plastic in the presence of water, shrink with drought, and expand under the effect of freezing. Soil improvement, also known as soil treatment or stabilization, is a technique that has been introduced for many years with the primary goal of making soils capable of satisfying clay soil criteria [1]. This treatment is often performed to increase strength, reduce or increase permeability, reduce compressibility, and minimize the sensitivity of fine soil to changes in water content. Therefore, it is necessary to use other exterior materials to improve the geotechnical performance of the site [2]. Several studies have been conducted on the phenomena related to this type of soil. The soil treatment techniques vary according to their character, such as the treatment by adding rubber fiber [3], natural or produced and product materials [4-6], and the use of waste tires, ashes and sewage sludge, which have shown good potential for soil stabilization [7].

The use of sand as a stabilizing material is a fairly recent technique and has not been widely used yet. This techique consists of replacing part of the soil with sand. Studies on this subject showed that the addition of sand reduces the plasticity of the mixture (clay-sand), thus reducing its swelling potential [8-10]. This study aims to investigate the effect of the addition of coarse alluvial sand on the mechanical behavior of marl soil to use it in road construction.

II. MATERIALS AND METHODS

This study used two main materials in the composition of the test soils: alluvial sand and marl soil. The marl soil used came from Gueddid in the Djelfa region, Algeria, where it was extracted at a depth of about 1m. After extraction, the soil was placed in plastic bags and transported to the laboratory for preparation and execution of geotechnical identification and characterization tests. This soil was extracted in its natural red color state in compact clods, therefore, it is difficult to mix it with sand to produce the test soils. For this purpose, a laboratory procedure was followed to transform it into a very fine powder, as shown in Figure 1, without modifying the chemical nature of the grains. Granular analysis was carried out by sieving grains superior to 80μm, according to NF P 94-056 [11]. On the other hand, a sedimentation method was carried out for grains with a diameter lower than 80μm, according to NF P 94-057 [12]. Figure 2 shows the particle size distribution of marl soil.

Fig. 1. Marl soil.

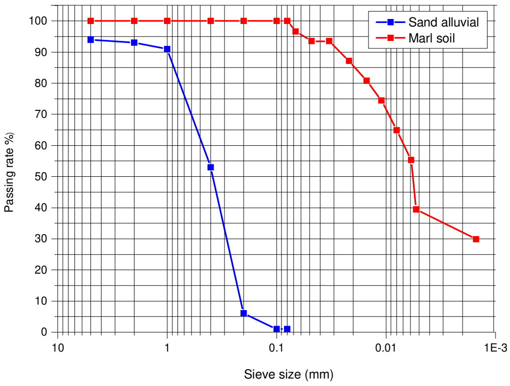

Fig. 2. Granular distribution of alluvial sand and marl soil.

The alluvial sand (Figure 3) used for soil reconstitution was extracted from Wade Messaad in Djelfa, and is commonly used to produce concrete on construction sites. The standardized test by dry voice according to NF P 18-560 [13], determines the distribution of the grains of sand according to their sizes, as seen in the granular curve shown in Figure 2. Table I summarizes the results of the sand equivalent test, specific gravity, and apparent density of this alluvial sand.

Fig. 3. Alluvial sand.

TABLE I. PHYSICAL CHARACTERISTICS OF ALLUVIAL SAND

Characteristic	Specific weight (g/m^3)	Apparent density (g/m^3)	Sand equivalent test (%)
Value	2.91	1.48	94.6

The main objective of the experimental study was to evaluate the effect of adding coarse alluvial sand at different percentages on the mechanical properties of marl soil, such as Atterberg limits, soil compressibility as determined by an odometer test, and shear strength using the direct shear test. The experimental study was conducted at the NLHC in Djelfa, Algeria. The samples were prepared in the following way:

- Soil samples were dried for 24 hours.
- Preparation of marl and alluvial sand mixtures with mass percentages of the latter being 0%, 3%, 5%, and 10%.
- Humidification of the samples to a water content of 20%.
- Mixing of the samples.
- Compacting samples by static compression.
- Sampling using identical volumetric rings of samples of the same mass, height, and section.

The Atterberg limits were tested according to NF P 94-051 [14]. The test was carried out in two phases. The first was to study the Liquidity Limit (LL) of the water content, where a groove of standardized dimension, made in the soil and arranged in the Casagrande cup, closes under the action of 25 shocks applied in a standardized way. The second phase examined the Plasticity Limit (PL) of the water content, where a soil cylinder of diameter 3mm, made manually, cracks when it is lifted. Figure 4 shows a sample of the soil studied during the test.

Fig. 4. Procedure of the Atterberg limit test.

The odometer compression test is fundamental in the soil compressibility test, according to XP P 94-090-1[15], as it is a direct application of consolidation theory. This test allows an evaluation of the amplitude of the settlements of the structures, as well as their evolutions. The study of ground deformation can be reproduced in the laboratory thanks to the Terzaghi odometer. This device simulates the following configurations: a very large horizontal surface compared to its thickness, a uniform vertically applied load, and the possibility of zero horizontal displacements. The apparatus for axial loading a cylindrically shaped specimen placed in a rigid cylinder and measuring the variation ΔH of the height H separates the upper and lower faces of the specimen, which eventually becomes submerged, are in contact with draining disks. Figure 5 presents the test procedure.

The direct shear test was performed according to the NF P 94-071-1 [16] standard. This test determines the mechanical properties of the soil through the rectilinear shear of a sample under constant load. The shear test was used to plot the intrinsic curve of the soil under study and determine its internal friction angle ϕ and its cohesion C. Figure 6 shows a mixture of the studied soils after the test.

Fig. 5. Compressibility test on a soil sample studied during its execution.

Fig. 6. Soil sample studied after the direct shear test.

III. RESULTS AND DISCUSSION

A. Atterberg Limit Test Results

Figure 7 shows the results of the Atterberg limit test for the studied mixtures. The results show that the plasticity index decreased in all mixtures as the alluvial sand content increased, from 24.4% to 19.2% after adding 3% sand and continuing to decrease until 11.5% for 10%. This indicates a change in consistency after the addition of sand and an improvement in soil workability. Several studies have also shown the same trend [5, 7].

B. Compressibility Test Results

Figures 8 and 9 show the initial and final void index and compressibility curves, respectively, of the mixtures. The results show that the coefficient of compressibility decreases with an increase in alluvial sand content, and therefore the compression of the soil decreases when the sand content increases.

The classification of soils according to their compressibility and void ratios was given in [17]. The compression coefficients Cc of the studied soils can be determined from the curves in Figures 8 and 9. Table II illustrates the classification of the studied mixtures. The results obtained show that the marl-sand soil mixtures are classified as moderately compressible soils.

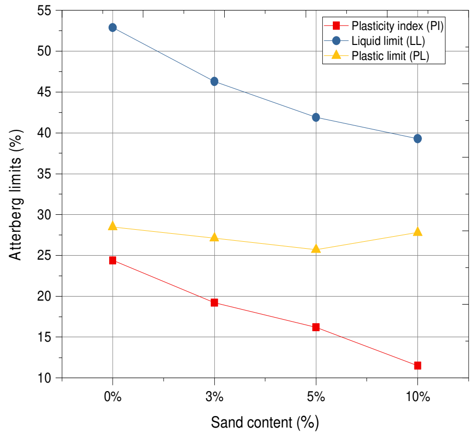

Fig. 7. The plasticity index and the limits of liquidity and plasticity of the studied soils.

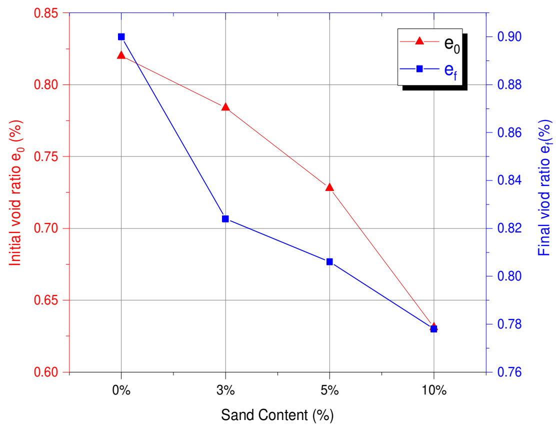

Fig. 8. Ratio of initial and final voids of mixtures.

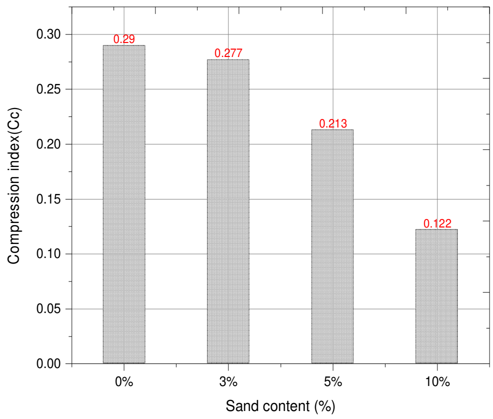

Fig. 9. Compression index of mixtures.

TABLE II. MIXTURE CLASSIFICATIONS

Mixture with sand content (%)	$Cc/(1+e_0)$	Soil class
0	0.159	Moderately compressible
3	0.169	Moderately compressible
5	0.1233	Moderately compressible
10	0.063	Moderately compressible

C. Shear Strength Test Results

The shear test evaluates the mechanical characteristics of soils, i.e. the cohesion C, the angle of friction ϕ, and the shear strength τ_{max} at the moment of failure. All tests for the different mixtures were carried out the same way as for the case of pure marl soil. Figure 10 shows the friction angle and the cohesion of the studied mixtures. The results show an increase in the angle of friction and a decrease in the cohesion of soils with an increase in the alluvial sand content. The angle of friction increases from 26.58° for pure marl soil to 30.82°, 36.21°, and 40.42° for sois with alluvial sand content of 3%, 5%, and, 10%, respectively. This indicates that the incorporation of alluvial sand improves the shear strength of the marl soil.

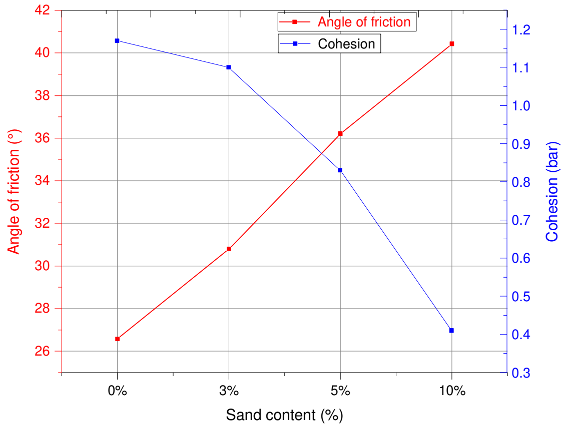

Fig. 10. Angle of friction and cohesion of mixtures.

IV. CONCLUSION

This study evaluated the mechanical behavior of marl soil treated with alluvial sand at a content of 3, 5, and 10% by weight. The main conclusions of this experimental study are:

- Changes in the Atterberg limits increase the liquidity limit and the plasticity limit, and, as a result, the plasticity index decreases. The decrease in the plasticity index indicates an improvement in soil workability.
- The compressibility coefficient of the mixtures decreases as the alluvial sand content increases.
- The angle of friction increases proportionally with the content of alluvial sand in the mixtures, whereas a rapid decrease in cohesion was observed when the alluvial sand content increased. This suggests that the addition of alluvial sand increases the shear strength of the marl soil.

The advantages of improving fine soils by using local materials are technical and economic, as they improve both stability and cost, which are very important factors to consider in a project.

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