

EXPERIMENTAL STUDY OF THE EFFECT OF HYDRAULIC BINDERS ON THE BEHAVIOR OF SILTY SAND

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Abstract

Introduction. This paper presents a laboratory study investigating the mechanical behavior of silty soil reinforced with hydraulic binders (cement and lime) using a direct shear apparatus. A series of direct shear tests was performed on silty soils treated with hydraulic binders. **Methods.** The tests were conducted at a relative density of 50 %, under three normal stresses, with cement and lime contents of 0, 1, 3, 5, and 7 %, and a water content of 10 %. **Results.** The shear strength of cement-treated silt increases with cement content up to 6 % and then stabilizes. For lime-treated silt, the shear strength decreases at a lime content of 1 % and then stabilizes; thus, the contractive behavior increases with higher lime content. The internal friction angle increases with cement content and then stabilizes, with a slight decrease observed at a cement content of 7 %. Cohesion increases linearly with cement content. Lime addition enhances soil contractiveness; cohesion increases slightly up to a lime content of 3 % and then decreases. For the silt treated with the cement–lime mixture, the test results show that shear strength increases with normal stress compared to the untreated soil.

Keywords: silty soil; cement; lime; content; shear; internal friction angle; cohesion.

Introduction

The problem of soil instability — affecting infrastructure such as buildings, factories, bridges, and roads — is a major concern for public authorities in terms of land use planning. Soil improvement and reinforcement techniques therefore remain an important topic in civil engineering, particularly in the field of geotechnics. These methods aim primarily to enhance mechanical properties by increasing strength and permeability, and by reducing the deformation that occurs under applied loads. Several techniques are currently used to strengthen or improve soil resistance, including compaction, vibroflotation, installation of compacted sand micropiles, drainage, ballast columns, and stabilization through the addition of hydraulic binders.

Several laboratory studies investigated the influence of lime and cement on weak silty soils (Åhnberg, 1996; Akpokodje, 1985; Asghari et al., 2003; Baxter et al., 2011; Consoli et al., 1998; Haeri et al., 2006; Heathcote and Piper, 1994). At lower cement contents and under low confining pressures, soils treated with Portland cement exhibited the highest shear strength (Haeri et al., 2006). Additional studies by Banoune (2016), Boutouil (1998), and Kazi Aoual-Benslafa et al. (2014) examined the

influence of hydraulic binders on soil behavior and their effects on shear strength and other mechanical properties. Other researchers focused on the influence of lime on the hydro-mechanical behavior of silt–lime mixtures. Kevin et al. (2013) reported that the mechanical properties of treated soil are governed by microstructural organization, and that lime treatment enhances mechanical performance. The hydro-mechanical properties of soil are significantly improved by lime addition (Osula, 1996). Cement and lime also have a notable effect on the material's microstructure (Osula, 1996). Their addition modifies the flocculation and aggregation of fine clay particles and affects the grain size distribution. Mateus et al. (2016) conducted axial compression tests on sand–cement mixtures (3 % and 7 % cement content) with 10 % water and evaluated five curing periods. Their results show that mixtures with higher cement contents develop lower void ratios, leading to increased shear strength. Marri et al. (2012) emphasized the importance of cementation degree and confining pressure on the stress–strain behavior of cemented sand; the effect of cementation is more pronounced at low confining pressures and diminishes as confining pressure increases. Boutouba et al. (2019) investigated the role of cement content in the mechanical behavior

of sand and found that cement addition significantly increases shear strength, internal friction angle, and cohesion. They concluded that cement content has a substantial impact on the strength of cemented soils. Of all the studies conducted to date on the effect of lime or cement content on silt, none has provided a complete description of the physico-mechanical mechanism or its effects on both the microstructure and the macroscopic behavior. In this study, we investigate the effect of lime and cement content on the shear strength and mechanical behavior of Chlef silty sand, and examine how mechanical properties (friction angle and cohesion) vary to assess their potential use as a foundation base or foundation layer for road, quay, airport, and railway projects.

Experimental Program
Materials and Experimental Device

The silty sand used in this study was collected from the Zebabdja locality in the town of Oued Fodda, located about 15 kilometers from Chlef (Fig. 1). The fine particles in this soil are slightly plastic, with a plasticity index $I_p = 14.7\%$, as confirmed by the methylene blue test ($VBS = 2.66$), indicating a medium-plasticity soil. The physical characteristics



Fig. 1. Soil extraction area (Zebabdja, Chlef)

of this soil are presented in Table 1. The lime was obtained from the Hasasna industrial zone in the municipality of Saida, and the Chlef cement used is a product of the ECDE company (Algeria).

Tables 2 and 3 show the characteristics of the cement and lime used in the mixtures. Figs. 2 and 3 show the test apparatus and sample preparation process. Fig. 4 illustrates the particle size distributions of the sandy soil alone and of the soil–cement mixtures. The uniformity and curvature coefficients are almost identical to those of the original soil's grain size distribution. Numerous studies have been carried out to examine the behavior of Chlef sand (Aouali et al., 2019; Arab, 2008, 2009; Arab et al., 2014; Della et al., 2011; Djafar Henni et al., 2013; Merabet et al., 2020).

Fig. 5 illustrates the evolution of the plasticity index as a function of cement content. Fig. 6 shows the shape of the soil grains obtained using a scanning electron microscope, along with the microstructure of Chlef silty sand. All samples

Table 1. Physical characteristics of the soil

Physical characteristic	Value
Fine content ($D < 80 \mu\text{m}$)	5.47 %
D_{10}	0.13 mm
D_{30}	0.28 mm
D_{60}	0.35 mm
C_u (uniformity coefficient)	2.69
C_c (curvature coefficient)	1.72
Natural water content	14.75 %
W_L (liquid limit)	28.28 %
W_p (plastic limit)	13.58 %
I_p (plasticity index)	14.7 %
VBS (methylene blue value)	2.66
Fines fraction	15 %
Sand fraction	85 %



Fig. 2. Experimental equipment used for soil preparation in the laboratory



Fig. 3. Sample preparation: (a) original soil; (b) cement; (c) lime

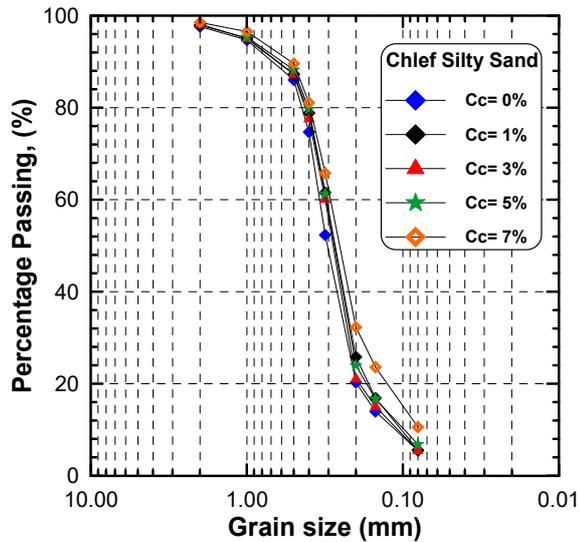


Fig. 4. Grain size distribution curves for the silt-cement mixtures

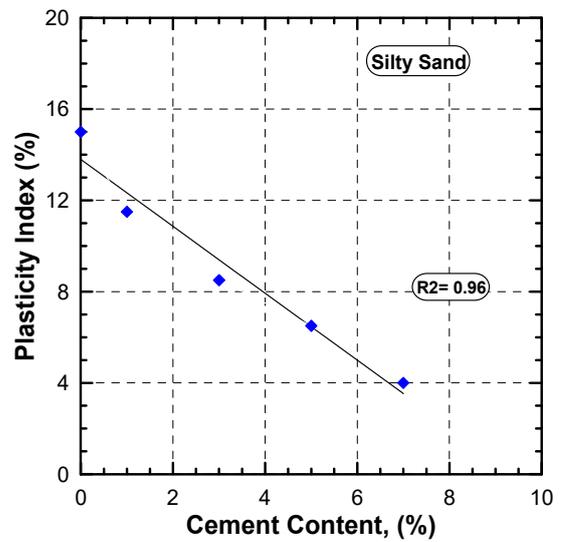


Fig. 5. Variation of the plasticity index with cement content

Table 2. Chemical and mineralogical compositions of cement

Chemical composition	(%)
SiO ₂	21.64
Al ₂ O ₃	4.90
Fe ₂ O ₃	4.35
CaO	65.82
SO ₃	1.78
MgO	0.93
K ₂ O	0.55
Na ₂ O	0.29
Mineralogical composition	(%)
C ₃ S	55.46
C ₂ S	21.49
C ₃ A	6.99
C ₄ AF	11.81

Table 3. Chemical and mineralogical compositions of lime

Chemical composition	(%)
SiO ₂	1.77
AL ₂ O ₃	5.81
Fe ₂ O ₃	2.63
CaO	78.01
MgO	1.15
K ₂ O	0.17
Na ₂ O	0.13
SO ₃	0.55

were prepared at a relative density of 50 % and sheared under normal stresses $\sigma_n = 100, 200,$ and 300 kPa, with a water content of 10 %. The soil was transported from the deposit to the laboratory

in 50 kg bags. After sieving the soil and retaining only the silty fraction, the samples were prepared by blending the silty soil with cement or lime in a mixer for about one hour. To ensure homogeneity, the mixtures were then placed in a chamber at 25°C and 90 % humidity for curing periods of 1, 7, 14, and 28 days. Each sample was formed in three layers, with the mass of each layer determined according to the initial relative density ($Dr = 50$ %). Each layer was poured into the mold and manually

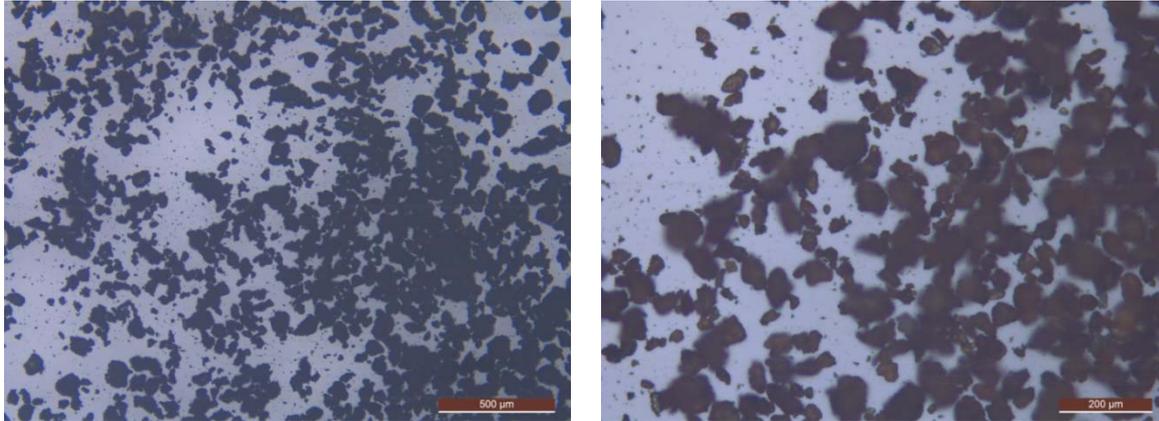


Fig. 6. Scanning electron microscope (SEM) image of the silt used

compacted — typically with 25 strokes — until the desired height was achieved.

The analyzed material is reddish in color and relatively fine, with 5.47 % of its particles smaller than 0.08 mm. It is of medium plasticity ($I_p = 14.7\%$), as confirmed by the methylene blue test ($VBS = 2.66$). For each sample preparation, the mass of each mixture used to reconstitute the sample in the shear box was calculated with reference to the initial relative density (I_d), using the following equation (Ben-salah et al., 2022; Merabet et al., 2020):

$$m_s = (V_T \times g_s) / (1 + e_{max}(1 - Dr) + Dr \times e_{mi}) \quad (1)$$

Tables 2 and 3 present the chemical and mineralogical compositions of cement and lime, respectively.

Test Results and Discussion

Effect of cement content

Figs. 7a, 8a, and 9a illustrate the evolution of the shear strength of silty sand mixed with cement. All samples were prepared at an average relative

density ($Dr = 50\%$), with the cement content (C_c) varying from 0 to 7 %. The samples were consolidated and sheared under normal stresses of 100, 200, and 300 kPa, respectively. The test results clearly show that the addition of cement has a significant effect on the strength of the mixtures. For samples sheared under σ_n of 100 kPa (Fig. 7a), the shear strength increases with increasing cement content. For samples sheared under normal stresses of 200 and 300 kPa, the strength increases up to a threshold cement content of $C_c = 5\%$, and then decreases (Figs. 8a and 9a). This reduction in strength beyond 5 % can be attributed to internal erosion within the treated soil. Figs. 7b, 8b, and 9b show the evolution of vertical displacement as a function of horizontal displacement. It is observed that the addition of cement significantly increases the contractive behavior of the soil. These findings are in close agreement with results reported in the literature.

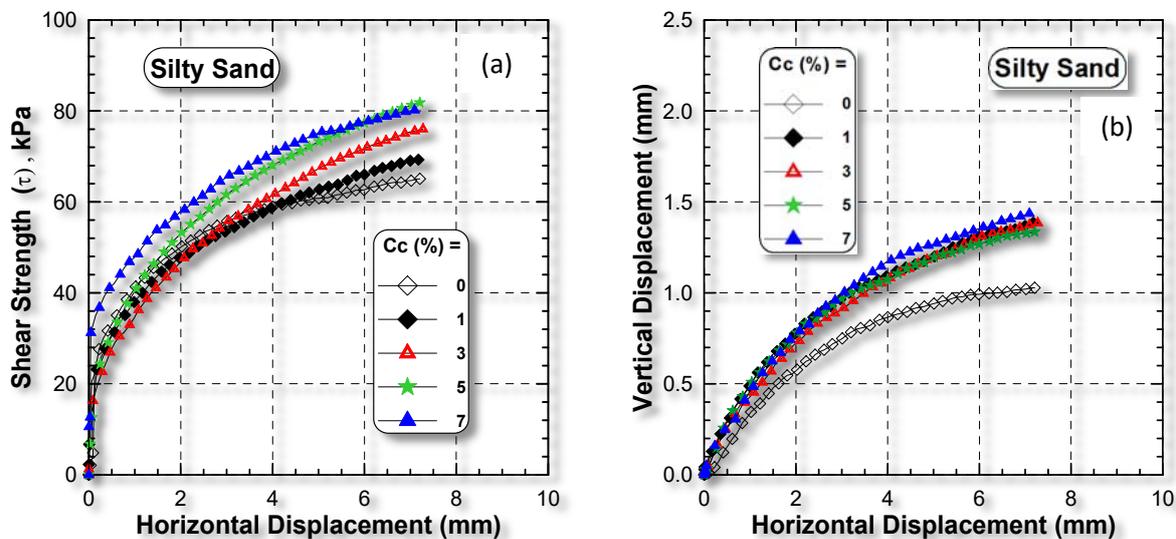


Fig. 7. Evolution of shear stress versus horizontal displacement for silty sand mixed with cement ($\sigma_n = 100$ kPa, $Dr = 50\%$)

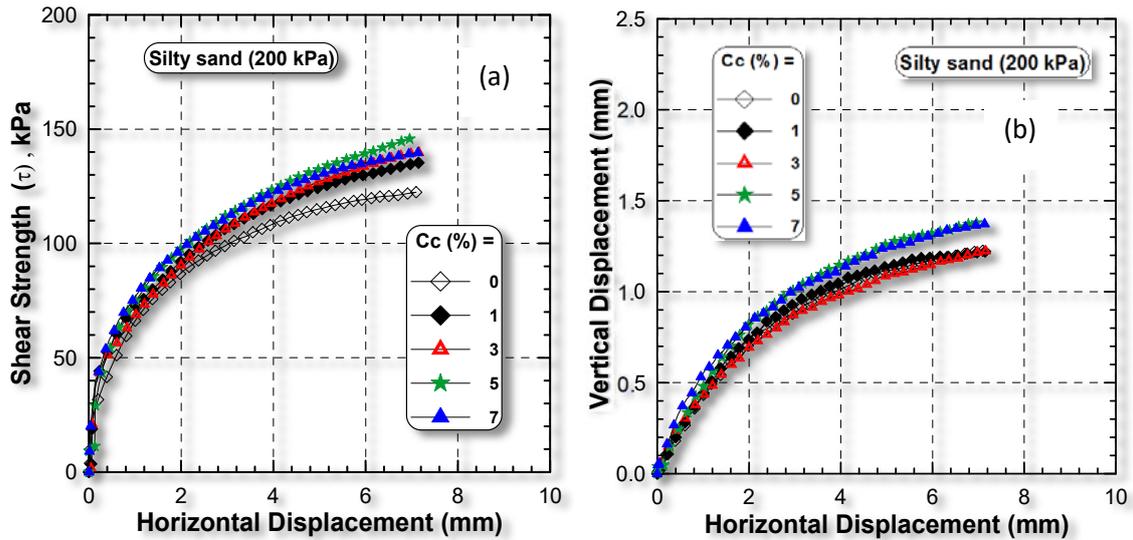


Fig. 8. Evolution of shear stress versus horizontal displacement for silty sand mixed with cement ($\sigma_n = 200$ kPa, $Dr = 50\%$)

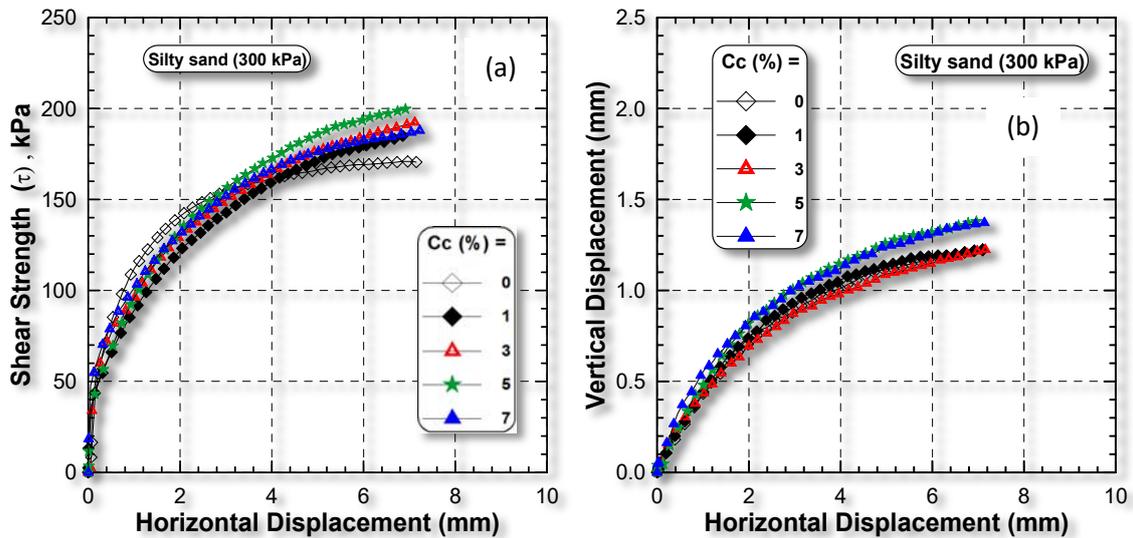


Fig. 9. Evolution of shear stress versus horizontal displacement for silty sand mixed with cement ($\sigma_n = 300$ kPa, $Dr = 50\%$)

Fig. 10 shows the evolution of shear strength as a function of cement content for samples sheared under normal stresses $\sigma_n = 100, 200,$ and 300 kPa. It can be observed that the shear strength of the mixtures increases with increasing normal stress σ_n , and also with increasing cement content up to $C_c = 5\%$, after which it decreases. Fig. 11 illustrates the evolution of cohesion as a function of cement content. Cohesion increases linearly with increasing cement content. This increase in cohesion is attributed to the good adhesion between the silt and the cement.

Fig. 12 shows the evolution of the friction angle as a function of cement content for sand–cement mixtures. It can be observed that the friction angle

increases with increasing cement content and then stabilizes; a slight decrease in the friction angle is noted at a cement content of 7% .

Effect of lime content

Figs. 13, 14, and 15 show the results of shear tests on sand–lime mixtures with an initial relative density of $Dr = 50\%$, consolidated and sheared under normal stresses $\sigma_n = 100, 200,$ and 300 kPa, with lime content Cl varying from 0 to 7% . Fig. 13a illustrates the evolution of shear strength as a function of horizontal displacement for sand–lime mixtures. It can be observed that shear strength decreases with increasing lime content up to 1% , and then increases as the lime content continues to rise. The initial decrease in shear strength after

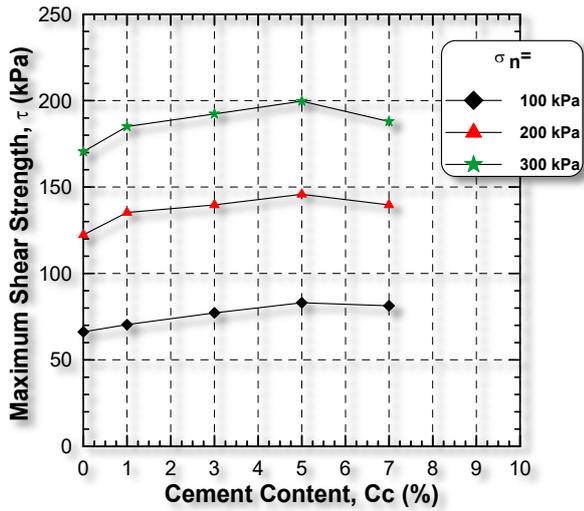


Fig. 10. Evolution of maximum shear strength versus cement content (Cc)

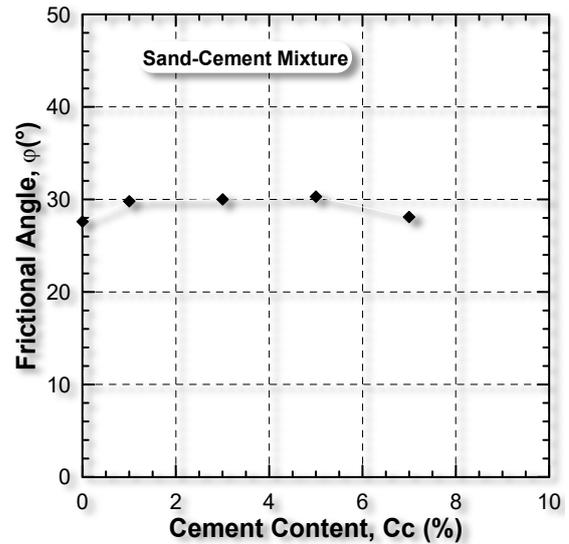


Fig. 12. Evolution of the friction angle versus cement content (Cc)

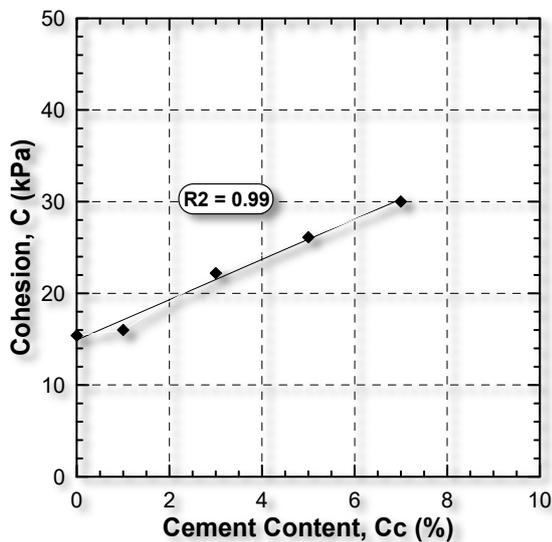


Fig. 11. Evolution of cohesion versus cement content (Cc)

lime addition is attributed to the increased porosity of the mixture. Fig. 13b shows the evolution of vertical displacement versus horizontal displacement for sand–lime mixtures. The results indicate that increasing lime content enhances the contractive behavior. Similar observations were made for the samples consolidated and sheared under normal stresses of 200 and 300 kPa (Figs. 14 and 15). However, for samples subjected to higher consolidation stresses, a clear improvement in dilatant behavior was observed during shearing, indicating favorable mechanical performance for deeper soil layers (Figs. 14 and 15).

Figs. 15a and 15b present the shear test results for the sand–lime mixtures with a relative density of $D_r = 50\%$, sheared under a normal stress of $\sigma_n = 300$ kPa, with lime content C_l varying from 0 to

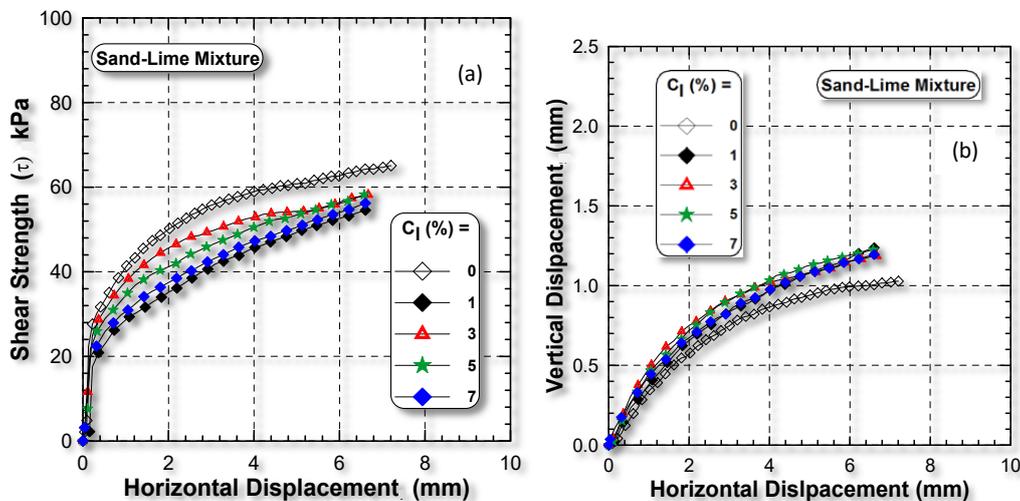


Fig. 13. Evolution of shear strength versus horizontal displacement for sand–lime mixtures ($\sigma_n = 100$ kPa, $D_r = 50\%$)

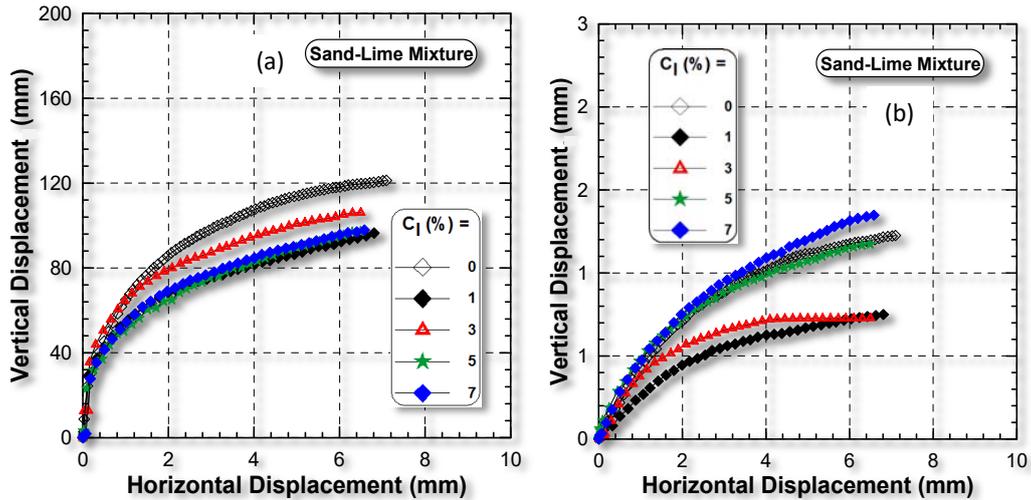


Fig. 14. Evolution of shear strength versus horizontal displacement for sand–lime mixtures ($\sigma_n = 200$ kPa, $D_r = 50\%$)

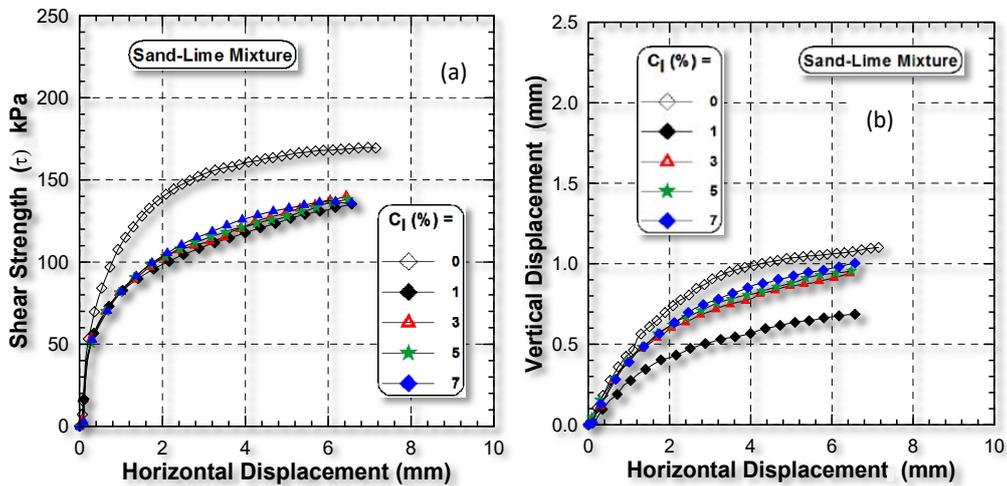


Fig. 15. Evolution of shear strength versus horizontal displacement for sand–lime mixtures ($\sigma_n = 300$ kPa, $D_r = 50\%$)

7 %. Fig. 15a shows shear strength versus horizontal displacement for sand–lime mixtures. The results indicate that shear strength decreases with increasing lime content up to 1 %, and then increases as the lime content continues to rise. Fig. 15b shows the evolution of vertical displacement versus horizontal displacement for sand–lime mixtures. It can be observed that increasing the lime content slightly reduces contractiveness up to $C_l = 1\%$, beyond which contractiveness decreases only slightly.

Fig. 16 shows the evolution of shear strength for soil–lime mixtures with lime contents ranging from 0 to 7 %, consolidated and sheared under normal stresses $\sigma_n = 100, 200,$ and 300 kPa. It can be observed that shear strength decreases for all mixtures at a lime content of 1 %, then increases slightly, and subsequently stabilizes up to a lime content of 7 %.

Fig. 17 shows the evolution of cohesion as a function of lime content for sand–lime mixtures. The results indicate that cohesion increases slightly up to a lime content of 3 %, and then decreases as the lime content increases further.

Fig. 18 shows the evolution of the friction angle for sand–lime mixtures. The results indicate that the friction angle decreases at a lime content of 1 %, and then stabilizes as the lime content increases up to 7 %.

Effect of lime–cement on shear strength

Another series of shear tests was carried out in the shear box on soil samples mixed with 6 % cement and 3 % lime; these samples were sheared under normal stresses of 100, 200, and 300 kPa. The fractions of 6 % cement and 3 % lime had shown good performance in the previous shear tests. A clear improvement in shear strength with

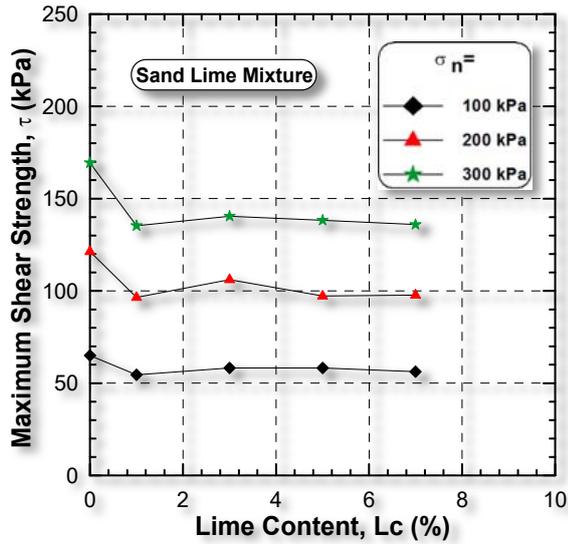


Fig. 16. Evolution of shear strength versus lime content

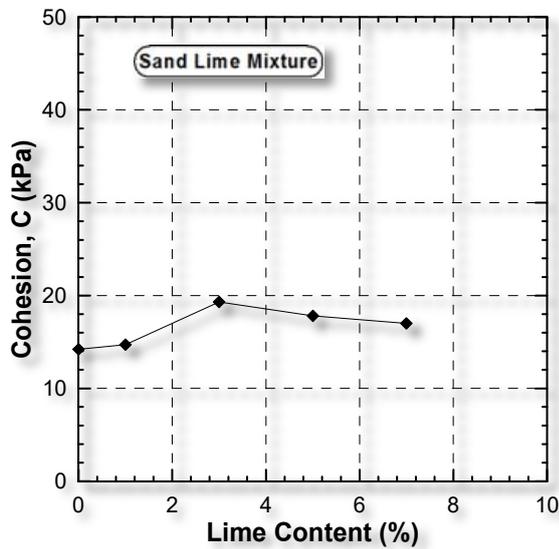


Fig. 17. Evolution of cohesion versus lime content

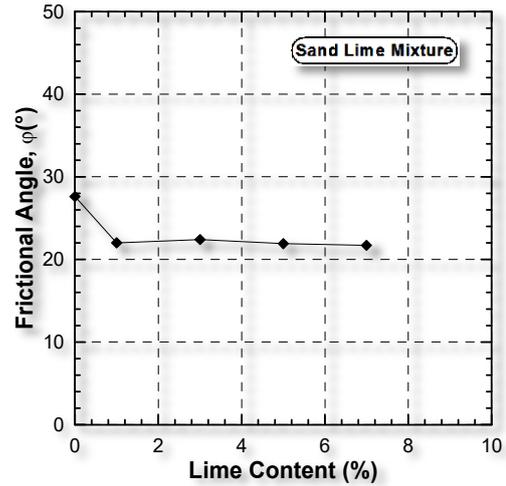


Fig. 18. Evolution of the friction angle versus lime content

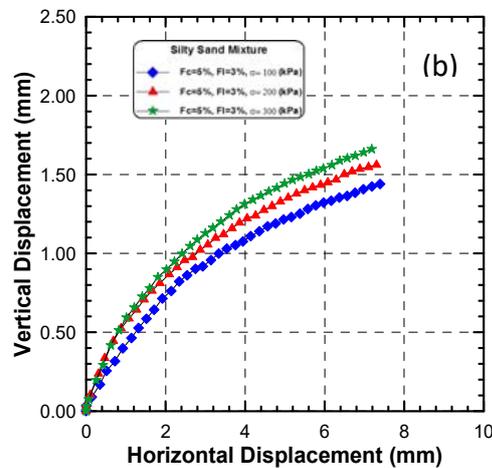
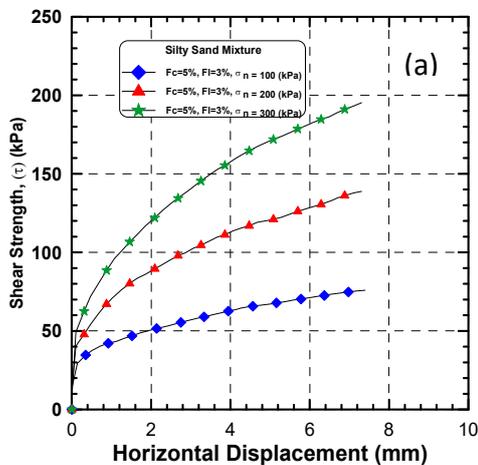


Fig. 19. Effect of cement and lime content on shear strength: (a) evolution of shear strength versus horizontal displacement; (b) evolution of vertical displacement versus horizontal displacement

increasing normal stress is observed (Fig. 19a). Fig. 19b illustrates the evolution of vertical displacement versus horizontal displacement. It can be seen that increasing the normal stress leads to an increase in contraction. These results are in full agreement with those reported in the literature.

Fig. 20 shows the evolution of shear strength for the sample mixed with 6 % cement and 3 % lime as a function of normal stress, compared with the untreated soil. The test results indicate a linear increase in shear strength with increasing normal stress, with correlation coefficient $R^2 = 0.98$. Fig. 20 also shows that the soil treated with cement and lime is more resistant than the untreated soil ($R^2 = 0.99$).

Conclusion

In this study, a series of direct shear tests was carried out on silty sand mixed with cement and lime, with an initial relative density of $D_r = 50 \%$, for the stabilization of coastal soils in Ténès (Chlef, Algeria). The samples were consolidated and sheared under

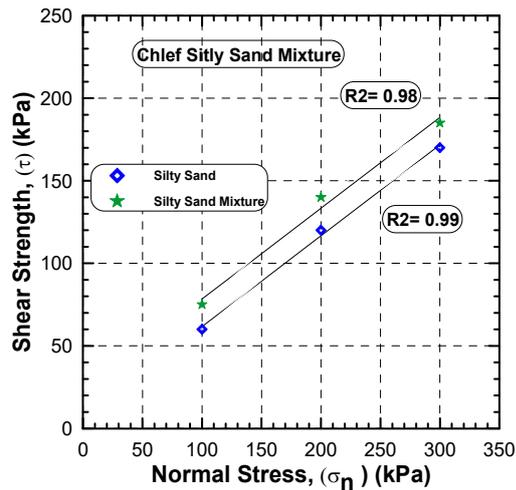


Fig. 20. Evolution of shear strength versus normal stress.

normal stresses ranging from 100 to 300 kPa, with a water content of 10 %, and cement and lime contents varying from 0 to 7 %, in order to examine the mechanical behavior of sand–cement and sand–lime mixtures and their influence on mechanical properties.

The main conclusions drawn from the test results are as follows:

- The shear strength of silt–cement mixtures increases with cement content up to 6 % and then stabilizes.
- Increasing cement content leads to a significant increase in the contractive phase of the samples.

- Higher normal stresses result in improved shear strength, accompanied by increased contractive behavior.

- For silt–lime mixtures, shear strength decreases at a lime content of 1 % and then increases with further lime addition; thus, contractive behavior increases with lime content.

- The presence of cement in the mixture has little effect on the friction angle; however, cohesion increases with increasing cement content.

- For sand–lime mixtures, shear strength decreases up to 1 % lime content and then stabilizes up to 7 %. A similar trend is observed for the friction angle, which decreases up to 1 % and then stabilizes. Cohesion increases slightly up to 3 % lime content and then decreases.

- For the silt–cement–lime mixture, the test results show a linear increase in shear strength with increasing normal stress, with correlation coefficient $R^2 = 0.98$. The treated soil exhibits significantly higher shear strength compared with the untreated soil.

Acknowledgments

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Abbreviations

- C: Cohesion
- Rd: Relative density
- Id: Initial density
- SEM: Scanning electron microscope
- Cc: Cement content
- Lc: Lime content
- e_{min} : Minimum void ratio
- e: Global void ratio
- e_{max} : Maximum void ratio
- γ_s : Specific weight of solids
- m_s : Specific mass

List of symbols

- ϕ : Internal friction angle
- σ_n : Normal stress
- τ : Shear strength

Units of measurement

- KPa: Kilopascal
- mm: Millimeter

References

- Ahnberg, H. (1996). Stress dependent parameters of cement and lime stabilized soils. In: *Grouting and Deep Mixing. Proceedings of the 2nd International Conference on Ground Improvement Geosystems*, May 14–17, 1996, Tokyo, Japan. Rotterdam: AA Balkema, pp. 387–392.
- Akpodjé, E. G. (1985). The stabilization of some arid zone soils with cement and lime. *Quarterly Journal of Engineering Geology and Hydrogeology*, Vol. 18, No. 2, pp. 173–180. DOI: 10.1144/GSL.QJEG.1985.018.02.06.
- Aouali, N., Benessalah, I., Arab, A., Ali, B., and Abed, M. (2019). Shear strength response of fibre reinforced Chlef (Algeria) silty sand: laboratory study. *Geotechnical and Geological Engineering*, Vol. 37, Issue 2, pp. 1047–1057. DOI: 10.1007/s10706-018-0641-5.
- Arab, A. (2008). Behavior of soils under monotonic and cyclic loading. PhD Thesis in Civil Engineering.
- Arab, A. (2009). On monotonic and cyclic behavior of silty sand. *Comptes Rendus Mécanique*, Vol. 337, Issue 8, pp. 621–631. DOI: 10.1016/j.crme.2009.08.001.
- Arab, A., Sadek, M., Belkhatir, M., and Shahrou, I. (2014). Monotonic preloading effect on the liquefaction resistance of Chlef silty sand: a laboratory study. *Arabian Journal for Science and Engineering*, Vol. 39, Issue 2, pp. 685–694. DOI: 10.1007/s13369-013-0700-4.
- Asghari, E., Toll, D. G., and Haerl, S. M. (2003). Triaxial behaviour of a cemented gravely sand, Tehran alluvium. *Geotechnical & Geological Engineering*, Vol. 21, Issue 1, pp. 1–28. DOI: 10.1023/A:1022934624666.
- Banoune, B. (2016). *Comportement mécanique et durabilité des matériaux routiers à différents dosages en sédiments fins*. PhD Thesis in Engineering.
- Baxter, C. D. P., Ravi Sharma, M. S., Moran, K., Vaziri, H., and Narayanasamy, R. (2011). Use of $\bar{A} = 0$ as a failure criterion for weakly cemented soils. *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 137, Issue 2, pp. 161–170. DOI: 10.1061/(ASCE)GT.1943-5606.0000414.
- Benessalah, I., Sadek, M., Villard, P., and Arab, A. (2022). Undrained triaxial compression tests on three-dimensional reinforced sand: effect of the geocell height. *European Journal of Environmental and Civil Engineering*, Vol. 26, Issue 5, pp. 1694–1705. DOI: 10.1080/19648189.2020.1728581.
- Boutouba, K., Benessalah, I., Arab, A., and Djafar Henni, A. (2019). Shear strength enhancement of cemented reinforced sand: role of cement content on the macro-mechanical behavior. *Studia Geotechnica et Mechanica*, Vol. 41, Issue 4, pp. 200–211. DOI: 10.2478/sgem-2019-0020.
- Boutouil, M. (1998). *Traitement des vases de dragage par solidification/stabilisation à base de ciment et additifs*. PhD Thesis in Applied Sciences. additifs. PhD Thesis in Applied Sciences.
- Consoli, N. C., Prietto, P. D. M., and Ulbrich, L. A. (1998). Influence of fiber and cement addition on behavior of sandy soil. *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 124, Issue 12, pp. 1211–1214. DOI: 10.1061/(ASCE)1090-0241(1998)124:12(1211).
- Della, N., Arab, A., and Belkhatir, M. (2011). A laboratory study of the initial structure and the overconsolidation effects on the undrained monotonic behavior of sandy soil from Chlef region in northern Algeria. *Arabian Journal of Geosciences*, Vol. 4, Issue 5–6, pp. 983–991. DOI: 10.1007/s12517-010-0178-2.
- Djafar Henni, A., Arab, A., Belkhatir, M., Saeed Hamoudi, M., and Khelafi, H. (2013). Undrained behavior of silty sand: effect of the overconsolidation ratio. *Arabian Journal of Geosciences*, Vol. 6, Issue 2, pp. 297–307. DOI: 10.1007/s12517-011-0365-9.
- Haeri, S. M., Hamidi, A., Hosseini, S. M., Asghari, E., and Toll, D. G. (2006). Effect of cement type on the mechanical behavior of a gravely sand. *Geotechnical & Geological Engineering*, Vol. 24, Issue 2, pp. 335–360. DOI: 10.1007/s10706-004-7793-1.
- Heathcote, K. A. and Piper, R. (1994). Strength of cement stabilised pressed earth bricks with low cement contents. *Journal and Proceedings, Royal Society of New South Wales*, Vol. 127, pp. 33–37.
- Kazi Aoual-Benslafa, F., Ameur, M., Mekerta, B., and Semcha, A. (2014). Caractérisation des sédiments de dragage du barrage de Bouhanifia pour une réutilisation. In: *13th National Days of Coastal Engineering – Civil Engineering, July 2–4, 2014, Dunkirk, France*, pp. 999–1006. DOI: 10.5150/jngcgc.2014.110.
- Kevin, L., Dimitri, D., Stephanie, B., Michel, L., (1913). Effects of lime and cement treatment on the physicochemical, microstructural and mechanical characteristics of a plastic silt. *Engineering Geology*, Volume 166, pp. 255–261. DOI: 10.1016/j.enggeo.2013.09.012
- Marri, A., Wanatowski, D., and Yu, H. S. (2012). Drained behaviour of cemented sand in high pressure triaxial compression tests. *Geomechanics and Geoengineering*, Vol. 7, Issue 3, pp. 159–174. DOI: 10.1080/17486025.2012.663938.
- Merabet, K., Benessalah, I., Chemmam, M., and Arab, A. (2020). Laboratory study of shear strength response of Chlef natural sand: effect of saturation. *Marine Georesources & Geotechnology*, Vol. 38, Issue 4, pp. 461–467. DOI: 10.1080/1064119X.2019.1595792.
- Mateus Forcelini, Gregório Rigo Garbin, Vítor Pereira Faro, Nilo Cesar Consoli. (2016). Mechanical Behavior of Soil Cement Blends with Osorio Sand. *Procedia Engineering*. Volume 143, 2016, pp. 75–81
- Osula, D. O. A. (1996). A comparative evaluation of cement and lime modification of laterite. *Engineering Geology*, Vol. 42, Issue 1, pp. 71–81. DOI: 10.1016/0013-7952(95)00067-4.

ЭКСПЕРИМЕНТАЛЬНОЕ ИССЛЕДОВАНИЕ ВЛИЯНИЯ ГИДРАВЛИЧЕСКИХ ВЯЖУЩИХ НА ПОВЕДЕНИЕ ИЛИСТОГО ПЕСКА

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Аннотация

Введение. В данной работе представлено лабораторное исследование механического поведения илистого грунта, укрепленного гидравлическими вяжущими (цементом и известью), с использованием прибора прямого среза.

Методы. Серия испытаний прямым срезом была выполнена на илистых грунтах, обработанных гидравлическими вяжущими. Испытания проводились при относительной плотности 50 %, под тремя уровнями нормальных напряжений, при содержании цемента и извести 0, 1, 3, 5 и 7 %, и влажности 10 %. **Результаты.** Прочность на сдвиг ила, обработанного цементом, увеличивается с ростом содержания цемента до 6 %, после чего стабилизируется. Для образцов, обработанных известью, прочность на сдвиг уменьшается при содержании извести 1 %, а затем стабилизируется; таким образом, с увеличением содержания извести усиливается контрактантное поведение грунта. Угол внутреннего трения возрастает с повышением содержания цемента и затем стабилизируется; при 7 % цемента наблюдается небольшое снижение. Сцепление увеличивается линейно с ростом содержания цемента. Добавление извести усиливает контрактантное поведение грунта: сцепление слегка увеличивается до содержания извести 3 %, а затем уменьшается. Для илистого грунта, обработанного смесью цемента и извести, результаты испытаний показывают увеличение прочности на сдвиг с ростом нормального напряжения по сравнению с необработанным грунтом.

Ключевые слова: илистый грунт; цемент; известь; содержание; сдвиг; угол внутреннего трения; сцепление.