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Research Article

SOIL DENSITY EFFECTS ON COMPRESSIBILITY AND EXPANSION BEHAVIOR

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ABSTRACT

Soil compressibility and swelling are key properties for the design and long-term performance evaluation of geotechnical structures. These deformation parameters directly influence the stability, settlements, and deformations of foundations, embankments, and retaining structures. Soil density is an essential parameter controlling deformation properties, particularly compression and swelling indices. Although widely studied, this relationship sometimes remains controversial, particularly for fine-grained cohesive soils. This research aims to further investigate the influence of density on Cc and Cs for an extended range of soils with low to high fines content. An experimental campaign of consolidation tests was carried out on clay-sand mixtures undergoing an imposed stress path. The results of this study reveal a negative correlation between compressibility and fines content, contrasted by a positive relationship with swelling. These contradictory findings are attributed to the predominant effect of density.

Keywords: Density; Consolidation; Compression index; Swelling index; Fines content

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1. INTRODUCTION

Soil compressibility has been a topic of significant interest in the geotechnical engineering field. Previous studies have explored the influential factors affecting this property. Alawaji [1] examined the compressibility characteristics of sand-bentonite mixtures wetted with solutions containing varying concentrations of $Ca(NO_3)_2$ and $NaNO_3$, observing a decrease in volume compressibility as the chemical concentrations increased. Complementary research by Phanikumar et al. [2] revealed that the volume compressibility coefficient and compression index declined with an increase in the sand content within clay-sand composite soils. The compressibility behavior of dense sands and gravels is generally lower than that of clays, but can be significant under high applied stresses [3]. Additionally, the presence of chemical precipitates and organic matter has been found to influence the compressibility of clayey soils [4]. Compaction is a widely employed technique to mitigate soil compressibility and hydraulic conductivity [5]. It has been established that increasing the soil bulk density leads to a reduction in the compressibility coefficient, while factors such as moisture content, organic matter, and clay content tend to increase the compressibility coefficient [6]. Improvements in the degree of compactness can result in gains in soil strength and reductions in soil compressibility and elasticity [7]. The swelling of compacted clays is a crucial problem, predominantly encountered in tropical, arid, semi-arid, and hyper-arid regions [8]. This issue is specific to certain clay soil types and is primarily associated with variations in their moisture content, affecting both surface and subsurface structures [9]. Moisture content variation is one of the most significant factors influencing swelling potential, with initially moist expansive soils exhibiting reduced swelling upon contact with water due to a decreased affinity for water [10]. Swelling behavior is also influenced by factors such as clay content, clay mineralogy, and placement conditions [9]. This research investigates the influence of density on the compression and swelling behavior of consolidated sand-clay mixtures. By varying the fines content in overconsolidated samples, the study will analyze the impact of density on the mechanical properties of the mixtures, considering the strong relationship between density and fines content.

2. MATERIALS AND METHODS

2.1 Identification of Materials

The primary materials employed in this geotechnical study were sand and clay. Sand is a non-cohesive granular material that is frequently used as a plasticity regulator for clay in research applications [11]. Conversely, clay is a fine-grained, cohesive material that can undergo consolidation processes. A mixture of these two material types can represent the textural composition of clay, silt, and sand [12]. The clay utilized in this study was sourced from a site near the Ceram Divindus-Remchi ceramic tile production facility in northwestern Algeria. This clay is commonly referred to as "blue clay" and is used as a raw material in the manufacturing of wall ceramics. According to the Unified Soil Classification System (USCS) [13], this clay material is classified as a low plasticity clay (CL). The sand employed in this research was a fine, natural sand obtained from the Bouihi deposit, also located in northwestern Algeria. This sand is commonly utilized as a construction material for mortar preparation. The USCS [13] classifies this sand as poorly graded (SP). The specific properties of the clay and sand materials are provided in Table 1 and illustrated in Figure 3.

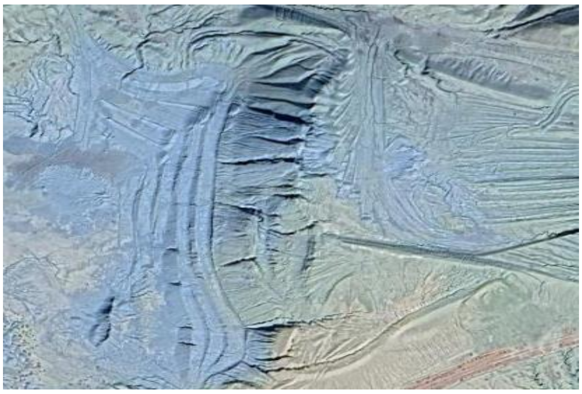

Fig.1. Location of the clay extraction site - Ceram Divindus-Remchi (northwest Algeria)

Fig.2. Location of the El Bouihi sand deposit (northwest Algeria)

Table 1. Properties of the Materials

	Clay	Sand	Standard
W_L%	46	-	NF P94-051 [14]
W_P%	24	-	
I_P%	22	-	
$\Upsilon_s(KN/m^3)$	26.52	26.43	NF P94-054 [15]
% 2 mm	100	100	NF EN 933-1 [16]

% 80 µm	100	1.54	
% 2 µm	36	-	NF P94-057 [17]
Cu	-	2.14	/
Cc	-	0.95	/

2.2 Preparation of the mixtures

The sand and clay materials, approximately 100 kg of each, were transported to the laboratory. They were then subjected to oven drying at a temperature of 110°C for 24 hours to remove any residual moisture. After this drying process, the materials were sealed in laboratory-grade plastic bags and stored in a designated storage area. The study examined six specific mixtures composed of the dried sand and clay, with the precise proportions presented in Table 2.

Testing was conducted on the clay-sand mixtures at various water contents. The objective was to determine the optimal water content that provided the desired characteristics. The samples were prepared by adding different amounts of water and then carefully and uniformly filling a cylindrical mold with a volume of 7.914 x 10-5 m^3 (as shown in Figure 7) by hand. Subsequent measurements were taken to evaluate the physical properties, including dry unit weight, void ratio, and degree of saturation. The obtained results are presented in Figures 4-6.

Table 2. Proportion of clay and sand

	Mixture 1	Mixture 2	Mixture 3	Mixture 4	Mixture 5	Mixture 6
Clay %	100	90	80	70	60	50
Sand %	0	10	20	30	40	50

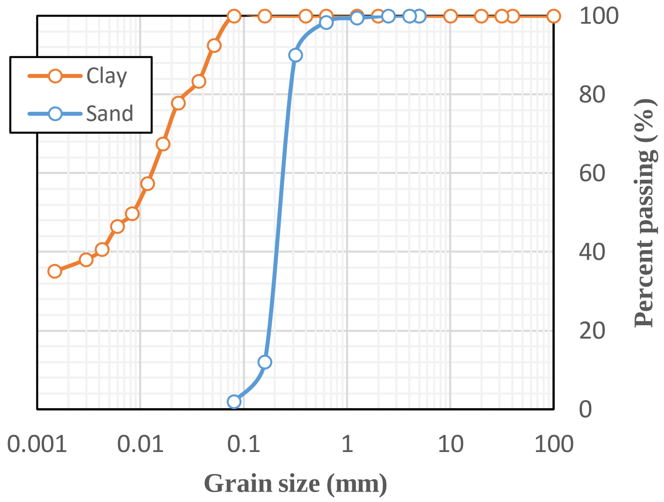

Fig.3. Grain size distribution curves for clay and sand

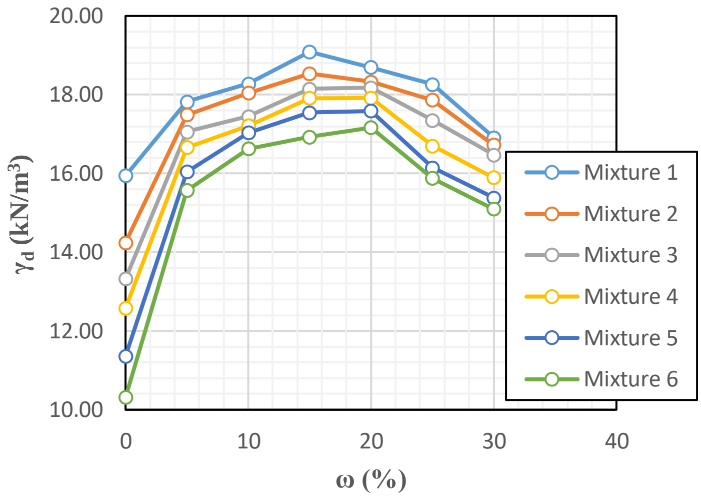

Fig.4. Dry unit weight as a function of water content

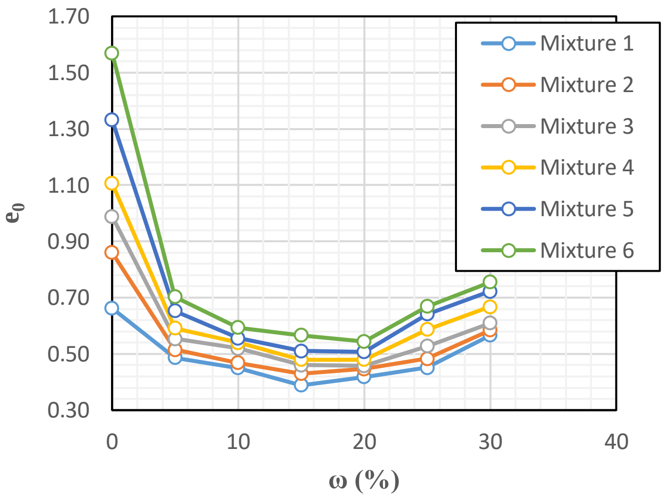

Fig.5. Void ratio as a function of water content

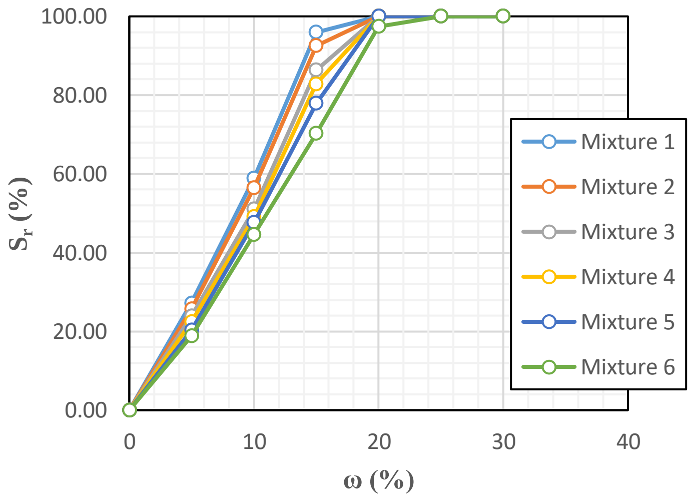

Fig.6. Degree of saturation as a function of water content

The data presented in Figures 4-5 demonstrate that, for most of the mixtures, a water content between 15% and 20% provides maximum compaction across all the mixtures. This suggests that a specific quantity of water will be required to achieve the ideal density in these mixtures. In contrast, Figure 6 indicates that a water content of 25% results in complete saturation for all the mixtures. Consequently, it was decided to systematically use 25% water content for the preparation of the test specimens. This decision was made because this value would enable verification of the consolidation criterion according to Terzaghi's postulate [18], and it would subsequently allow for more precise observation and analysis of the consolidation behavior of the samples. Table 3 presents the mean physical characteristics of the mixtures at a water content of 25%.

Fig.7. Sample before consolidation

Fig.8. Sample under consolidation

Table 3. Physical parameters of soil mixtures at 25% of water content

	Mixture 1	Mixture 1	Mixture 1	Mixture 1	Mixture 1	Mixture 1
γ_d **(kN/m^3)**	18,26	17,87	17,35	16,70	16,15	15,88
e_0	0,45	0,48	0,53	0,59	0,64	0,67
S_r **(%)**	100,00	100,00	100,00	100,00	100,00	100,00

2.3 Consolidation and Stress Path

After determining the optimal water content of the mixtures to be 25%, specimens were prepared in cylindrical molds with a volume of 7.914 × 10-5 m^3 and subjected to various stress paths. The adopted methodology involved applying a consolidation stress (σ'_c) on the specimens and then reducing this stress to a vertical effective stress (σ'_v) in such a way as to achieve a target OCR.

For this purpose, consolidation cells were utilized (as shown in Figure 8), equipped with lever arms that amplify the applied load by a factor of 10. The overconsolidation ratio and the stress path applied to the specimens are presented in Table 4. During the consolidation tests, the stress applied to the soil samples was doubled at each successive loading increment. This progressive increase in the consolidation stress allowed for the observation and analysis of the soil's responses to increasing stress levels.

The time required to transition from one loading or unloading increment to the next in the consolidation cells was 24 hours. This time period was essential to allow the soil to stabilize and reach an equilibrium state under the newly applied stress. During these 24 hours, the soil underwent consolidation processes, during which the voids between particles reduced and the particles rearranged to adapt to the new stress.

Table 4. Overconsolidation ratio and applied stress path

OCR	σ'_c (kPa)	σ'_v (kPa)
1	25	25
2	50	25
4	100	25
8	200	25

3. RESULTS AND DISCUSSION

3.1 Compressibility curves

A compressibility curve represents the variation of the void ratio and sometimes the strain as a function of the logarithm of the applied stress. The void ratio is calculated from the settlements measured on the dial gauge using Eq. (1). The compressibility curves for the six soil mixtures are provided in Figures. 9-14.

$$e_i = e_0 - \left[\frac{\Delta h}{h_0}(1 + e_0)\right] \tag{1}$$

Where :

Δh : Settlement (mm)

h_0 : Specimen thickness (mm)

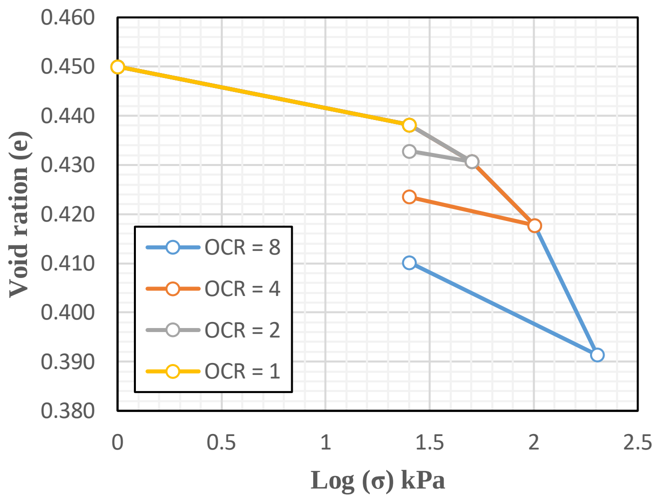

Fig.9. Mean compressibility curve for mixture 1

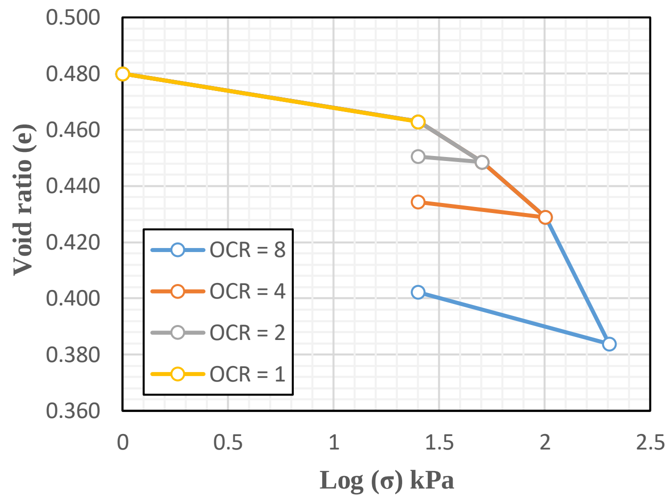

Fig.10. Mean compressibility curve for mixture 2

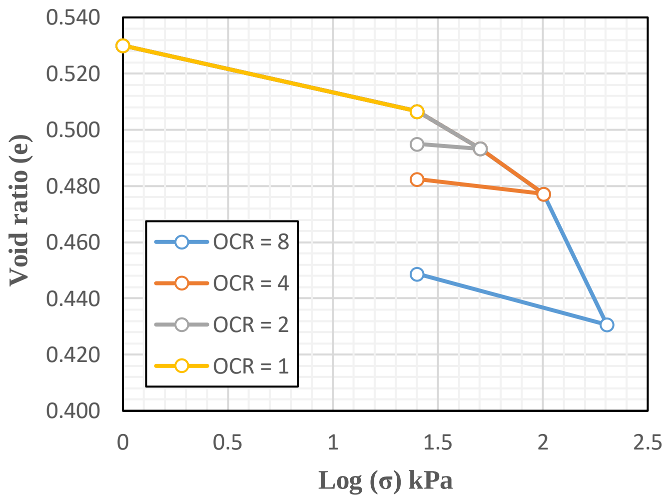

Fig.11. Mean compressibility curve for mixture 3

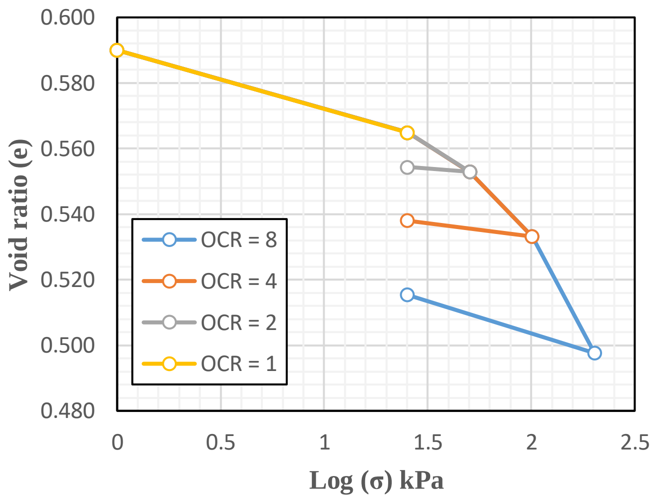

Fig.12. Mean compressibility curve for mixture 4

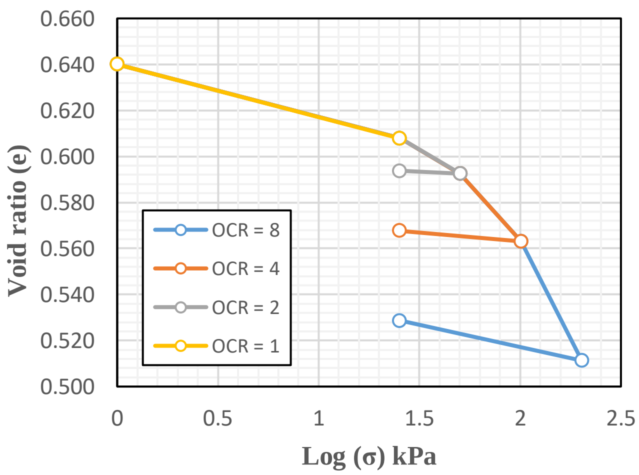

Fig.13. Mean compressibility curve for mixture 5

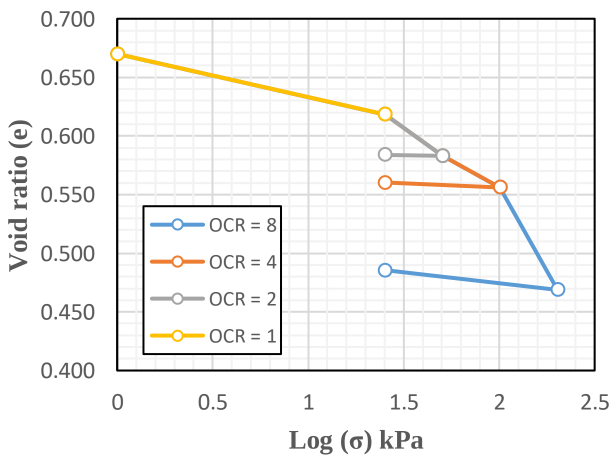

Fig.14. Mean compressibility curve for mixture 6

3.2 Effect of fines content and density on the compression index

The following examines the influence of fines content on the compression index of the six soil mixtures. It is well known that a high fines content, particularly of clay minerals, makes the soil more compressible due to their ability to retain water and rearrange under applied stress [19]. However, a negative correlation is observed between the fines content and the compression index, as shown in Figure 15.

The decrease in void ratio as a function of fines content is closely related to the significant deformation exhibited by the mixtures with lower fines content, as illustrated in Figure 16. In other words, a mixture with a lower fines content presents a more substantial deformation compared to a mixture composed of 100% clay.

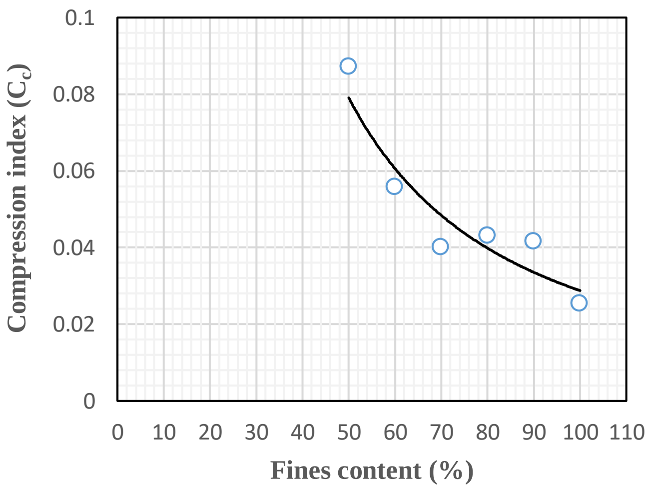

Fig.15. Variation of the mean compression index as a function of fines content

The deformation of materials is inherently linked to their density state, which means that a material in a less dense state tends to deform more than one in a denser state under the same loading [20]. Furthermore, Figure 17 shows that at the end of each consolidation increment, the mixtures with a lower fines content exhibit a lower density. This implies that their deformation will be more pronounced during the next loading increment compared to a mixture composed of 100% clay.

In summary, the soil mixtures with a lower fines content have a reduced initial dry density (γ_{d0}), which makes them more compressible. Consequently, even with the same water content and degree of saturation, these mixtures exhibit a higher compression index.

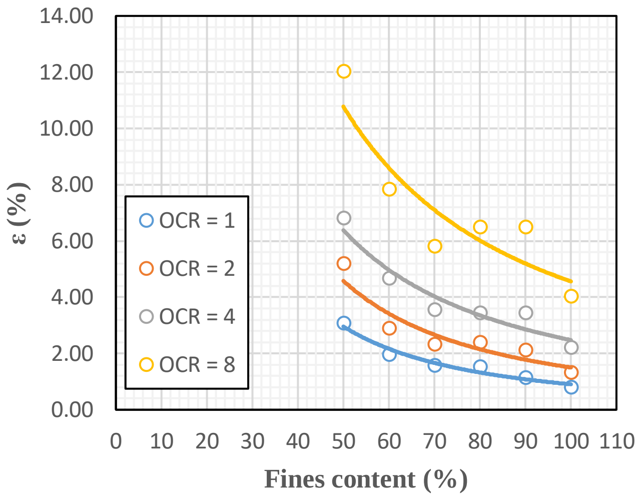

Fig.16. Mean strain at the end of consolidation for each overconsolidation ratio (ocr) for the six mixtures

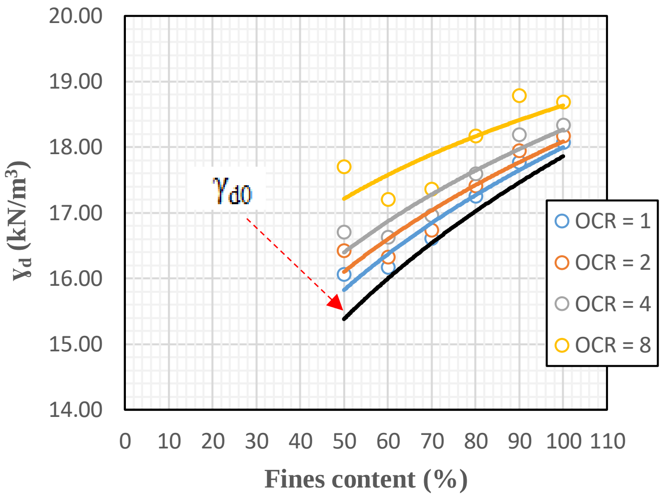

Fig.17. Mean dry unit weight at the end of consolidation for each OCR of the six mixtures

3.3 Effect of fines content and density on swelling index

In the present study, it is observed that the swelling of the materials exhibits a correlation with the fines content and density. Specifically, the swelling index increases as a function of the fines content in the mixtures, as demonstrated in Figure 18. This finding is also supported by several research studies, including the one conducted by Basma et al. [21].

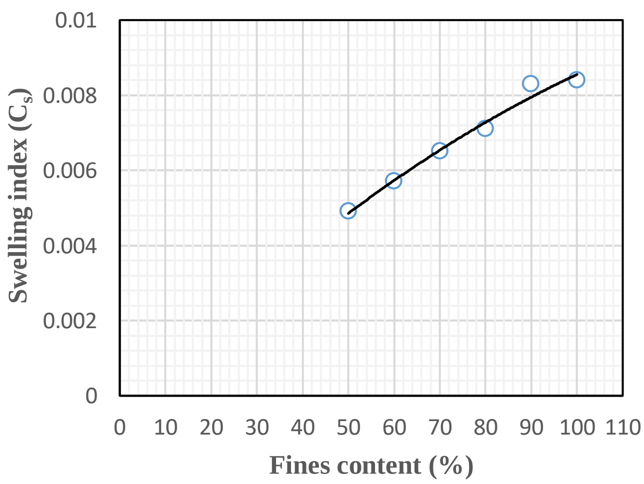

Fig.18. Variation of the mean swelling index as a function of fines content

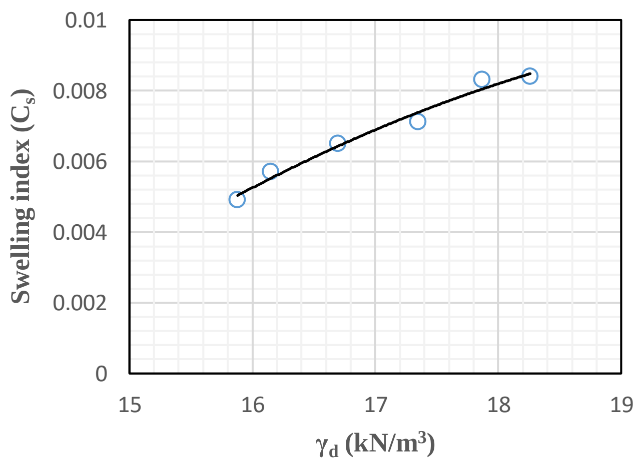

Fig.19. Variation of the mean swelling index as a function of initial dry unit weight

In addition to the relationship between fines content and swelling index, it is also noted that the swelling index increases proportionally with density, as shown in Figure 19. This observation is further supported by the research carried out by Villar et al. [22]. In short, mixtures with a lower fines content have a lower initial density (γ_{d0}), which results in a lower swelling capacity. Consequently, despite having the same moisture content and degree of saturation, these mixtures exhibit a lower swelling index.

4. CONCLUSION

This work has focused on the impact of soil texture, more specifically the fines content, on key geotechnical properties such as compressibility and swelling of materials. In the common mindset of practitioners, clayey soils exhibit strong compressibility and swelling behavior compared to soils with lower fines content. This research is driven by the need to better understand this hypothesis. Based on consolidation tests on samples with the same water content and degree of saturation, the results obtained allow the following conclusions to be drawn:

- A negative correlation was observed between fines content and compression index. This can be explained by the initial density of the material.
- A positive correlation was found between fines content and swelling index, mainly due to the final density after unloading.

These results show that soil particle size, and more specifically its fines content, has a significant influence on consolidation behavior, with different effects on compression and swelling indices depending on the initial and final conditions of the material.

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