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THE SWELL-SHRINK PROPERTIES OF INTACT AND DISTURBED CLAYEY AND MARLY SOILS: THE DISTURBANCE EFFECT

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ABSTRACT: The occurrence of droughts in recent decades has prompted researchers to pay closer attention to soil shrinkage. It is no longer appropriate to assume that surface soils in temperate countries are always saturated. When using traditional geotechnical identifications for soil classification based on swelling and shrinkage, the soil density is not consistently considered as a crucial parameter, nor is the state of the soil (intact or disturbed) or the degree of soil cementation. This article highlights the importance of studying the soil in its intact state to accurately represent its behavior on-site. The microstructure of undisturbed soil differs from that of disturbed soil and governs its macroscopic behavior. The method and level of soil disturbance have an impact on the results, depending on whether the focus is on shrinkage or swelling behavior and cementation. This research demonstrates that disturbed samples of clayey soils (Romainville green clay) exhibit lower shrinkage amplitude than intact clayey soil samples, whereas disturbed marly soil samples (Argenteuil blue marl) show the opposite trend. Furthermore, depending on the disturbance method, the swelling amplitude of intact soil samples may be higher or lower than that of disturbed soil samples. The results indicate that conducting a swelling test on W-disturbed samples and a shrinkage test on C-disturbed samples allows us to assess more closely the behavior of intact soil samples. In conclusion, recommendations for a more accurate assessment of the swelling-shrinkage potential of any given soil are provided, considering the test method and the level of disturbance of the sample.

Keywords: Swelling-shrinkage, Clay, Marl, Disturbance, Soil microstructure.

1. INTRODUCTION

Intact soils are commonly encountered beneath foundations, but when expansive clays are present, they can lead to structural issues and necessitate expansive repairs [1]. Engineers' practices have been impacted by dry summers and irregular rainfall patterns in recent decades, which affect the susceptibility of clay and marl soils to shrinking and swelling phenomena. These climatic changes influence the susceptibility of shrinking and swelling phenomenon of clay and marl. The main objective of this paper is to investigate how different soils respond to environmental variations and characterize their behavior under external hydraulic stress. Literature indicates that various parameters influence the swelling shrinkage process when soil moisture levels change. The cumulative effect of wet-dry cycles and the degree of soil consolidation [2]. Lithology, mineralogy, and geotechnical indices also play a role [3]. [4] demonstrated that the liquid limit significantly influences the shrinkage limit, air-entry suction, and compressibility of compacted samples. Soil disturbance, often accompanied by changes in dry density due to compaction or relaxation of cohesive forces between particles and aggregates, is another important parameter to consider. It is difficult to find a set of different intact soils with only one property (as density) varying naturally from one to another. It may conduct authors to study disturbed soils and to try to extrapolate their behavior on intact ones. Furthermore, when intact soils provided by coring are not available or when sampling is made using a hand auger, the engineer may also have to consider intact soil behavior from disturbed ones. Moreover, the classifications of intact expansive soils are almost exclusively based on parameters linked to soil particles after disturbance. The classifications are rarely based on direct measures of soil deformation except, for example, the Russian classification from SNIP that uses swelling amplitude as well as the [5]. The swelling soil classification by the US Environmental Protection Agency (EPA) is based on cation exchange capacity (CEC) and soil activity (Ac), or the one from the English Building Research Establishment [6] considers only the plastic index (PI) and the clay particle content in the soil. The swelling-shrinkage behavior of disturbed and compacted soils is largely studied not only in the earthwork domain to improve soil properties but also in agriculture [7], but it is rarely compared to intact soil behavior. As an exception, [8] found a 1:1 correlation between COLEstd (corresponding to the coefficient of linear extensibility linked to the shrinkage potential measured on intact soil) and COLErod, a parameter measured on remolded soil. Disturbance can modify the pore space architecture [9].

2. RESEARCH SIGNIFICANCE

This paper aims to enhance the understanding of the effect of clay and marl disturbance on their behavior under changing water conditions. Two disturbance modes, denoted as C and W, are applied to investigate which mode provides the best approximation of intact soil behavior and to evaluate whether deformations are over- or underestimated. Soil deformation is also correlated with changes in soil microstructure observed through environmental scanning electron microscopy and porosimetry via mercury intrusion. This study provides valuable insights into the swelling-shrinkage behavior of disturbed and compacted soils at different densities (detailed in another paper) and contributes to a better understanding of the behavioral differences between clay and marl soils, as well as between remolded and intact samples subjected to water variations.

3. MATERIALS AND METHODS

3.1 Material and Characterization

Intact blocks representing the two primary geological formations in the Parisian sedimentary basin, which are known to cause building pathologies during droughts, were sampled from a quarry. These blocks are referred to as Argenteuil blue marl (BM and BMJ2) and Romainville green clay (GC and GC2). Physico-chemical analysis and geotechnical tests were conducted to determine the soil characteristics, and the results are presented in (Table 1). Mineral phases in the soil and the semi-quantification of the clay fraction were identified.

3.2 Sample Preparation

Two different preparation methods, denoted as "cut" (C) and "wet" (W), were employed on the GC, GC2, BM, and BMJ2 soil samples to investigate the effect of soil preparation. The "C" disturbed sample (Fig. 1) involved cutting the soil into small pieces, coarse crushing to sizes between 1-3 mm, and drying at 40°C for a minimum of 24 hours. The soil was then wetted to achieve the water content of intact soil. After 24 hours for homogenization, it was compacted in an oedometer ring using a static press to attain the same void ratio as the intact soil. On the other hand, the "W" disturbed sample (Fig. 2) was created by mixing the soil with water (with a water content greater than 1.5 times the liquid limit) for 24 hours to form a mud-like consistency. After drying in a thin layer in a large, flat container, a similar preparation protocol to the "C" method was applied.

Table 1 Geotechnical identification and physico-chemical characteristics measured on intact BM, BMJ2, GC and GC2.

Parameters		GC	GC2	BM	BMJ2
Color		Green/yellow		Blue	
Moisture w (%)		27	30	30	27,2
Density ρ (g/cm^3)		2,02	1,97	2,07	1,98
Dry density ρ_d (g/cm^3)		1,52	1,54	1,47	1.56
Initial void ratio e_o		0,77	0,78	0,83	0,74
w_{OPN} (%)		27,2	n.m.	30	n.m.
$\rho_{d\ OPN}$ (g/cm^3)		1,23	n.m.	1,26	n.m.
Liquid limit w_L (-)		76	67	81	68,8
Plasticity limit w_P (-)		37	30	35	25,6
Plasticity index I_P		39	37	46	43,2
V_{bs} (g/100g)		9,5	7,6	5,5	3,9
CEC (meq/100g)		39,5	26,5	22,3	14,9
< 80µm fraction $C_{80\mu m}$ (%)		98,6	98	100	97
< 2µm fraction $C_{2\mu m}$ (%)		78,3	76,9	81	35
Saturation Sr (%)		97	100	97,6	98,5
Carbonates C_{CaCO3} (%)		3,1	5,8	34,4	66,9
Organic matter C_{OM} (%)		0,88	n.m.	3,22	n.m.
Global mineralogy	Calcite	Tr.	+	++	++++
	Dolomite	--	--	++++	--
	Quartz	++++	++++	++	+
	Clay	+	Pr.	+	Pr.
	Felspar	--	Pr.	--	Pr.
	Gypsum	--	--	--	--
	Hematite	--	--	--	Pr.
	Anatase	--	--	--	Pr.
Mineralogy of the clay in < 2µm fraction	M	35%	--	40%	--
	Mu/I	60%	75%	50%	75%
	K.	5%	25%	10%	10 %
	P.	--	--	--	15%

Notes: Tr: Trace, Pr.: Present, (M: Montmorillonite, Mu/I: Muscovite/Illite, K: Kaolinite, P: Palygoskite, Vbs: methylen blue adsorption value (NF P 94-068 standard), CEC: cation exchange capacity (method using cobaltihexamine ion exchange), wOPN and density at OPN: optimal moisture content and maximal dry density given by normalized proctor test), C CaCO3 : the carbonate content measured using NF P94-048 standard.

Fig.1 The “C” disturbed sample preparation (BM).

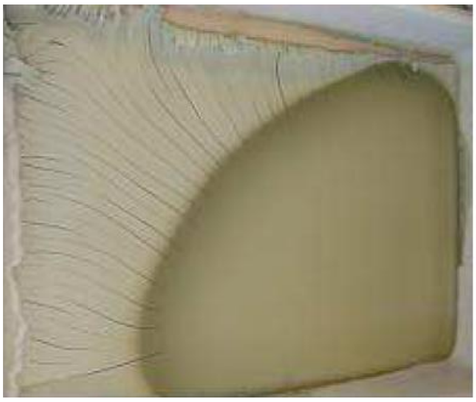

Fig.2 The “W” disturbed sample preparation (GC).

The samples were tested after a minimum of 24 hours of rest in a sealed double bag. Detailed information about the samples and the tests conducted can be found in (Table 2), which summarizes the characteristics of the samples and the specific tests performed.

3.3 Swelling and Shrinkage Protocol

The swelling-shrinkage test protocol applied to the C- or W-disturbed soils is based on a combination of methods. The free axial swelling test follows the approach outlined in the [10], and shrinkage test which takes into account the initial and final dimensions and mass of the sample, which are determined manually using a caliper and a balance, respectively. These measurements are taken at the initial water content and at zero water content after the sample has been dried under air and heated to 105°C. This test protocol is simple, rapid, and cost-effective. In addition to the conventional approach, an automated apparatus, as described by [11], was employed to measure continuous volume shrinkage and produce shrinkage curves (Fig.3).

The apparatus included an axial displacement captor and two or three lateral displacement captors, while the cylindrical sample mass and its dimensions were continuously recorded using a balance connected to a computer. The results are systematically presented in e-w% (void ratio vs. water content) and dV/V-w% (volumetric strain vs. water content) plots, with the saturation line calculated using a particle density of 2.7 g/cm^3.

Table 2 Sample preparation (I: intact soil; W: disturbed soil under mud form; C: disturbed soil after cutting; Sh: volumetric shrinkage test, Sw: free swelling test, M: manually measures, A: automated measures, (1) is related to initially saturated samples).

Sample	Preparation	Compaction	Test	Cylindric sample	w_o %	Initial density	Initial dry density
GC	I, W, C	Static	$Sw_{(1)}$ and $Sh_{(1)}$ (A)	D = 50 mm H = 30 mm	27%	2,02	1,52
GC2	I, W, C		$Sw_{(1)}$ and $Sh_{(1)}$ (M)		30%	1,97	1,54
BM	I, W, C		$Sw_{(1)}$ and $Sh_{(1)}$ (A)		30%	2,07	1,47
BMJ2	I, W, C		$Sw_{(1)}$ and $Sh_{(1)}$ (M)		27%	1,98	1,56

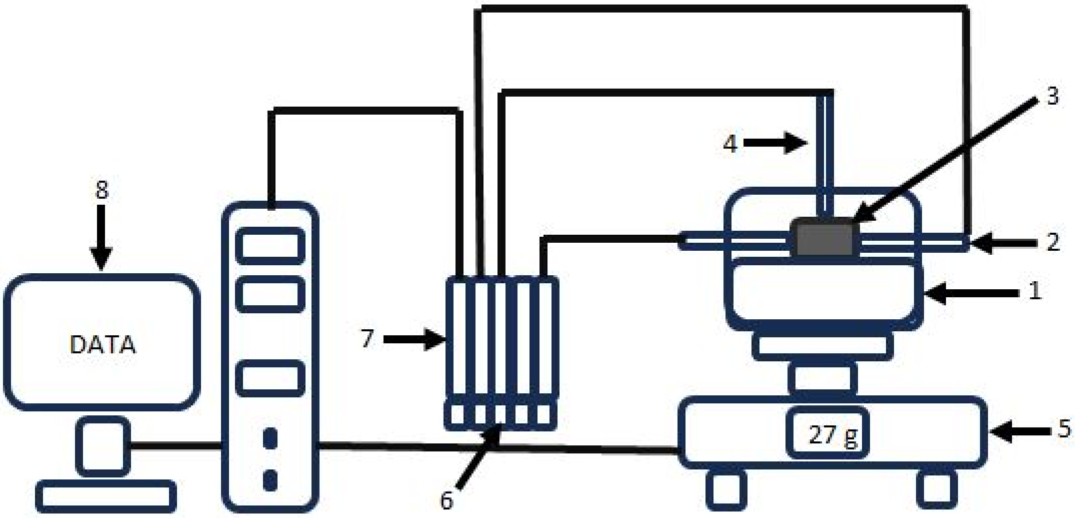

Fig.3 The free volume shrinkage automated apparatus 1- Cylindrical cell, 2- Two or three digital sensors (radial deformation), 3- Sample, 4- Digital sensor (axial deformation), 5- Balance, 6- TC connection, 7- USB interface RS485/RS232, 8- Automated acquisition with Labview software).

3.4 Microstructural Observations

The pore size distribution (PSD) of lyophilized samples was determined using porosimetry by mercury intrusion. The acquisition parameters were carefully selected to prevent disturbance of the soil during the intrusion and extrusion of mercury, while still allowing the system to reach a state of near-equilibrium as described by [12]. The results are presented in terms of differential intrusion (dV/dlogD, where V represents the volume of mercury introduced and D represents the pore diameter) and accessible porosity (n%), which is calculated based on the cumulative volume of mercury introduced into the sample. Microscopic observations were conducted using an environmental scanning electron microscope on the surfaces of freshly fractured samples, without any additional preparation steps. Secondary electron images were obtained using the low vacuum mode, which maintains a fixed humidity level of 2% in the analysis chamber.

4. RESULTS AND DISCUSSION

4.1 Soils Characterization

GC and BM exhibit similarities in terms of clay mineralogy, as indicated in (Table 1). Similarly, GC2 and BMJ2 also share similarities, with the latter containing palygorskite, which has an affinity for water adsorption but lacks the crystalline swelling properties of montmorillonite. In contrast, kaolinite, present in both GC and GC2, demonstrates a low water adsorption potential. In terms of overall mineralogy, the quantity and type of carbonates (calcian or magnesian) differentiate BMJ2 from BM marls. Both BM and BMJ2 marls have lower quartz content compared to the clayey soils of GC and GC2. In the case of BMJ2, the decrease in clay content correlates with an increase in carbonate content. The high liquid limits, plasticity limits, and plasticity indexes are influenced by the content of the < 2µm fraction and the nature of the clay minerals, particularly the presence or absence of swelling montmorillonite. Although the geotechnical identification does not exhibit significant differences between GC and BM samples or between GC2 and BMJ2, their shrinkage amplitudes vary. The decrease in the quantity of methylene blue (MB) adsorbed and the cation exchange capacity (CEC), are correlated with an increase in carbonates (and a decrease in quartz). The dry densities (ρ_d) of the four intact soils at the initial state are similar, while the saturation level is almost reached ($97\% < S_r < 100\%$). The normalized Proctor parameters (ρ_{OPN} and w_{OPN}%), as measured on BM and GC, are relatively similar, as shown in (Table 1). The C- or W-disturbed soil samples (Table 2) were prepared at the w_{OPN}% values of 27% for GC and 30% for BM. These water contents also correspond to the initial water content of the GC and BM soils when they were extracted from the quarry.

4.2 Amplitude of Swelling-Shrinkage Measured on Disturbed and Intact Clay and Marl

The results from the free swelling tests and free volume shrinkage tests (Table 3) indicate that intact soils exhibit different behaviors compared to disturbed soils, and the method of sample preparation has an impact on the strain amplitude during drying or humidification. Additionally, the behavior of green clay, characterized by low carbonate content ranging from 3.0% to 5.8%, differs from that of blue marl, which has a carbonate content of 35% to 67%. In all the swelling tests, the intact samples show lower deformation. Surprisingly, the W-disturbed samples, despite undergoing a more disruptive preparation protocol, appear to exhibit swelling deformation closest to that of the intact samples. In all cases, the marl and clay samples prepared by cutting the soil into smaller pieces exhibit higher deformation. It is worth noting that while cementation between particles is not present in GC or GC2, the small micrometric carbonates in BM and the locally observed carbonate aggregates in BMJ2 could contribute to the higher deformation in these samples. When examining the shrinkage results in Table 3, the behavior of clay and marl is less clear. The W- or C-disturbed samples of GC green clay seem to display smaller shrinkage strain compared to the intact soil, whereas GC2 shows similar deformation amplitudes. The behaviors of BM and BMJ2 are more consistent, with the W-preparation yielding the highest shrinkage amplitudes. It is interesting to note that while the W-preparation performs well in the shrinkage tests, it also provides the closest results to the shrinkage strain of intact soil in the swelling tests.

In conclusion, sample disturbance does not have the same impact on swelling and shrinkage. The choice of sample preparation method to approximate the sensitivity of intact soil to water variations depends on the specific test being considered. Furthermore, the swelling-shrinkage deformation of disturbed soil, denoted as Ass%, generally exceeds the deformation of intact soil. Testing remolded soil instead of intact soil tends to overestimate soil deformation, which leads to over dimensioning the foundation and reinforcing the structure.

Table 3 Initial and final states during shrinkage test (sh.) and swelling test (sw.) on intact and W or C disturbed BMJ2, BM, GC2 and GC samples.

	w_0 (%)	e_0 (-)	w_{sw} (%)	e_{sw} (%)	$\varepsilon_{sw}=\frac{\Delta H}{H_0}$ (%)	w_0 (%)	e_0 (-)	e_{sh} (%)	$\varepsilon_{sh}=\frac{\Delta V}{V_0}$ (%)	A_{SS} (%)
BM I	27,3	0,73	31,7	0,81	4,2	30	0,84	0,63	11,1	15,3 (-)
BM C	31,0	0,87	41,2	1,12	12,9 (+)	30,0	0,85	0,61	12,6	25,5 (+)
BM W	30,2	0,88	37,4	1,01	6,6 (+)	30	0,81	0,52	16,1	22,7
GC I	30,0	0,82	35,3	0,95	7,8* (+)	27,0	0,77	0,47	17,2	25 (+)
GC C	27,0	0,76	36,9	0,99	12,9	27,9	0,75	0,51	14,1 (-)	27 (-)
GC W	26,8	0,77	34,1	0,92	8,5	27,1	0,73	0,46	15,8	27,3
BMJ2 I	26,8	0,73	31,0	0,84	6,7	27,0	0,73	0,63	5,6	12,3
BMJ2 C	27,1	0,78	36,9	0,99	12,1	26,3	0,78	0,67	6,5 (+)	18,6 (+)
BMJ2 W	28,6	0,81	39,8	1,03	11,8 (+)	26,6	0,79	0,65	7,7	19,5 (+)
GC2 I	30,0	0,82	35,3	0,95	7,8	30,1	0,82	0,51	16,8	24,6
GC2 C	30,2	0,86	40,9	1,11	13,2	30,0	0,84	0,53	17,1	30,3
GC2 W	29,1	0,83	39,1	1,05	12,4	29,1	0,82	0,51	17,2 (+)	29,6

Notes: Swelling test on GC2 intact sample with C_{CaCO3} = 5,8% (whereas GC sample is characterised by C_{CaCO3} = 3,1%) and by a slightly higher initial water content and void ratio compared with GC sample.

A_{SS}% corresponds to the swelling-shrinkage deformation. (+) and (-) indicate if Ass (%) has to be considered respectively underestimated or overestimated considering the initial moisture content in swelling and shrinkage tests (ideally moisture contents have to be the same). (+) and (-) indicate also if ε_{sw} or ε_{sh} are respectively underestimated or overestimated considering the initial water content of the compared I-, C- and W- BM, GC, BMJ2 or GC2 samples.

Technically, this may reduce the occurrence of drought-related issues in houses, but it can increase the cost of the foundation. To accurately capture the real strain amplitude of natural soil, which cannot be replicated in laboratory conditions, it is important to collect undisturbed soil samples. Additionally, establishing a correlation between in-situ intact soil deformations and deformations measured in the laboratory will provide valuable insights.

4.3 Shrinkage Curves of Disturbed and Intact Clay and Marl Samples

The shape of the GC shrinkage curve shown in Fig. 4, presented in (ε%-w%) and (e-w%) plots, differs from that of BM. The GC shrinkage curves consistently exhibit the three major components commonly observed in soil shrinkage curves. The initial linear section at higher moisture content characterizes the drying of the sample along the saturation line, where the reorganization of the sample microstructure allows it to remain saturated while the volume decreases. Another linear section begins below the shrinkage limit (w_{sh}%), indicating drying without deformation. Between these two sections, residual shrinkage occurs, attributed to the drainage of micropores. While GC exhibits limited residual shrinkage that can be approximated by an exponential equation, intact or disturbed BM displays a broader zone of residual shrinkage that can be fitted with a linear equation. This atypical curve may consist of not three, but five sections. The air entry point shifts to a higher moisture content while the shrinkage limit (w_{sh}) reaches lower water content. Between these limits, a linear section and two exponential shrinkage sections can be distinguished. However, the effective shrinkage limit defined in the [13], which is the point of intersection between the initial and final linear sections of the curve (excluding the intermediate part), is similar to that of GC. After W-disturbance, the air entry point of the BM sample shifts towards lower moisture content, indicating the impact of disturbance on the microstructure and pore distribution in the soil. It is worth noting that the first part of the shrinkage curves for disturbed soil deviates slightly from the saturation line (the initial linear section is no longer parallel to the saturation line). This trend is typically attributed to the presence of macroporosity resulting from disturbance, as discussed by [14].

However, no structural shrinkage, characterized by a linear section connecting normal shrinkage to the saturation line associated with the drainage of macropores, was clearly identified. The dry density, which is similar to the density of intact soil and is close to the highest density achievable in the laboratory, does not allow for the presence of open macroporosity. Therefore, we hypothesize that the structural shrinkage associated with the drainage of the low content of macropores is combined with the drainage of micropores associated with the stable aggregates remaining after disturbance. This combination of both drainage mechanisms may explain the gradual shift of the curve.

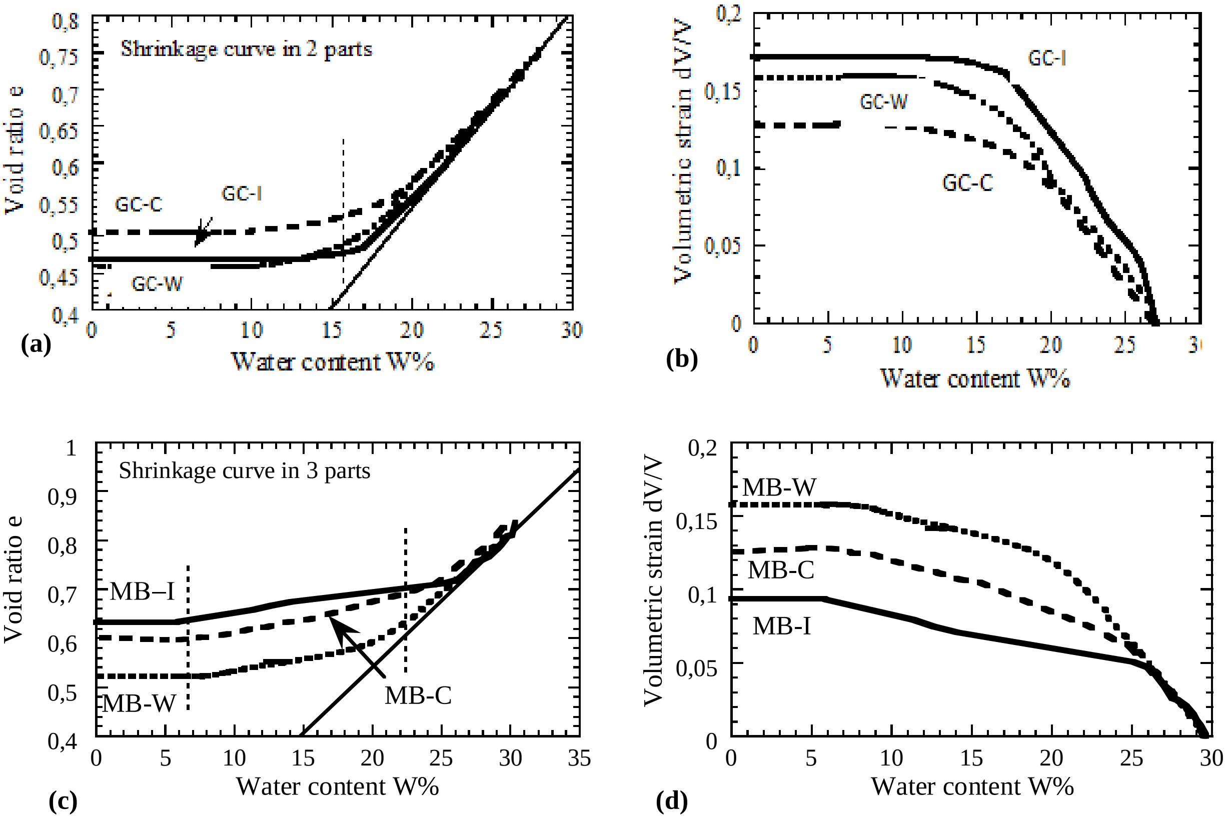

Fig.4 Effect of the mode of disturbance (C or W) on the shrinkage curve of GC (a, b) and BM (c, d) compared to the intact soil (I) in dV/V-w% and w%-e plans.

Concerning BM samples in Fig. 4, the atypical shape of the shrinkage curves appears to be specific to this marl and has not been observed as prominently in other marls studied so far or documented in the literature [15] mention of an "amazing" hump in the shrinkage curve of the Num clay loam and sand mixture.

Even though the soil is transformed into a mud-like form during W-disturbance, remolding cannot eliminate the atypical shape of the curve, which indicates the partial preservation of the intact microstructure within aggregates.

4.4 Discussion on Shrinkage Behavior Based on Microstructural Observations

The choice of disturbance mode, either C or W, leads to the reorganization of soil structure. The structural unit can be particles, aggregates, or blocks, which determine the behavior of the soil during shrinkage. In the W-disturbance protocol, the drying of the mud in large flat-bottomed bins results in the formation of layers. This step significantly contributes to stronger orientation of aggregates during quiet sedimentation. In intact soil, the aggregates are stable and exhibit slight orientation, particularly in the presence of carbonates acting as cement. Static compaction, both in C and W disturbance preparations, further aligns the blocks and aggregates, while secondary phases such as carbonates and quartz act as blocking points, preventing complete reorganization and shrinkage strain. Environmental SEM observations and PSD measurements (Fig.5) were conducted to validate these hypotheses and provide a better understanding of soil behavior during shrinkage. Intact green clay (GC) is characterized by pores ranging from nanometer to 0.1 µm, and there is a natural orientation of clay sheet particles inherited from the geological history. No aggregates are visible, but there is a presence of macroporosity contributing to the decrease in shrinkage deformation compared to intact soil behavior. The slightly parallel arrangement of aggregates and clay particles allows for significant shrinkage deformation, especially with the presence of deformable montmorillonite sheets. However, the presence of quartz particles does not prevent deformation, unlike carbonates. When GC soil is C-disturbed, it can be considered as an assembly of disoriented millimeter-sized blocks of intact soil, which are slightly oriented after compaction. The orientation at the particle or aggregate scale is preserved, resulting in shrinkage amplitudes similar to intact soil.

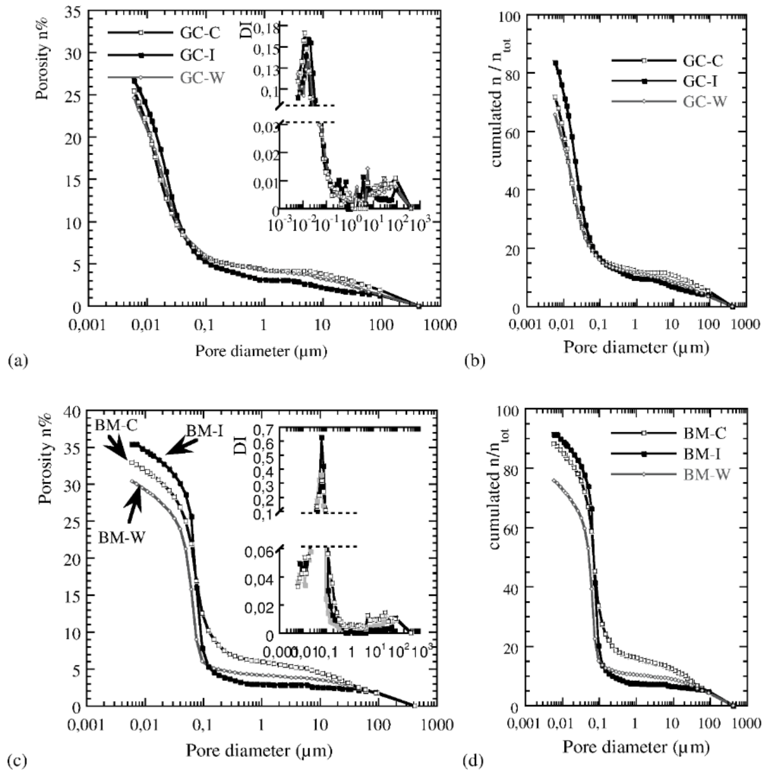

Fig.5 Cumulated porosity n% and n/n_{tot} versus the pore diameter (D in µm) of intact I, W- and C- disturbed statically compacted BM and GC after the drying at 105°C at the end of the shrinkage test. DI is the differential intrusion dV/d(logD) in mL/g.

However, the presence of disoriented blocks significantly reduces the strain deformation concentrated in macropores, which increases with disturbance.

The compaction is not sufficient to eliminate the effect of macroporosity resulting from the random arrangement of aggregates when soil is mixed with water. Macropores are present in both GC-C and BM-C samples, with a higher quantity in BM-C, balanced by a lower quantity of nanopores. When GC soil is W-disturbed, the particles, aggregates, and blocks produced by grinding are more oriented than in intact soil, leading to increased strain deformation of lenticular pores. The lower quantity of macropores and the higher quantity of nanopores in W-disturbed GC compared to C-disturbed GC support this hypothesis. However, the effect of block disorganization counteracts the increase in shrinkage strain, similar to C-disturbed soil. Consequently, GC-W is characterized by higher deformation than GC-C but lower than intact soils. Turning to the microstructure of BM, it can be described as clayey soil with carbonates replacing quartz, creating a rigid particle skeleton. Carbonates also contribute to the presence of pore families around 0.05-0.1 µm. The presence of carbonates in BM results in less shrinkage compared to GC at the same range of water content. C-disturbance does not eliminate the stiffening at the particle scale, as evidenced by the conservation of the shape of the shrinkage curve and the presence of the 0.1 µm pore family. However, the disorientation of millimeter-sized blocks allows for partial liberation of soil deformation by breaking the cementation. The released deformation at the block scale overrides the remaining effects of particle and aggregate stiffening, as well as the hindering effect of blocks on soil reorganization that tends to reduce shrinkage strain. In W-disturbed blue marl, the effect of block liberation remains, and it is reinforced by the partial orientation of particles and aggregates, resulting in an increase in volume strain. This orientation may occur in aggregates due to the intermediate mud form of the soil sample. The higher mobility of particles, facilitated by a stronger break in cementation, explains why W-disturbed BM samples exhibit the highest shrinkage strain compared to intact or C-disturbed marl. This behavior aligns with the higher strain observed in marl samples subjected to cyclic drying and wetting, where the rigid skeleton gradually breaks down.

5. CONCLUSIONS

The magnitude of soil shrinkage or swelling is influenced by various factors, including carbonate content and microstructure, which are significantly affected by disturbance. This study highlights the importance of sampling intact soil to accurately estimate soil deformation under foundations and roads. The behavior of cemented microstructures, such as carbonated marl, is not affected in the same way as clay by disturbance. While shrinkage tests on disturbed clay underestimate soil deformation, disturbed marl exhibits an increase in shrinkage deformation after disturbance. In all cases, remolded samples demonstrate higher amplitude of swelling deformation compared to intact soil. In situations were working with undisturbed soils is not feasible or too costly, remolded samples can be used. Indeed, the results presented in this publication indicate clearly that conducting a swelling test on W-disturbed samples and a shrinkage test on C-disturbed samples allows to assess more closely the behavior of intact soil samples, thus decreasing the cost of field investigations. This study will be continued by the setup of physical models in laboratory and on site to validate these results.

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